AIR FORCE JOURNAL of LOGISTICS

FALL
1981

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AFRP 400-1

VOL V
NO 4

FALL
1981

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Purpose The *Air Force Journal of Logistics* is a non-directive quarterly periodical published in accordance with AFR 5-1 to provide an open forum for presentation of research, ideas, issues and information of concern to professional Air Force logisticians and other interested personnel. Views expressed in the articles are those of the author and do not necessarily represent the estimated policy of the Department of Defense, the Department of the Air Force, the Air Force Logistics Management Center, or the organization where the author works.

Distribution Distribution within the Air Force is F through the PDO system based on requirements established for AFRP 400-1 on the basis of 1 copy for every 15 logistics officers, top three NCO's and professional level civilians assigned.

Subscription Subscriptions to this journal can be taken for $9.00 per year domestic ($11.25 foreign) through the Superintendent of Documents, Government Printing Office, Washington DC 20402. Single copies are $2.50 domestic ($3.15 foreign). Back issues are not available.

Authority to publish this periodical automatically expires on 3 August 1982 unless its continuance is authorized by the approving authority prior to that date.

"SOME OSD PERSPECTIVES ON LOGISTICS PLANNING AND DEFENSE READINESS: THE LAST DECADE AND A PREVIEW"

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The last 12 years have been the most interesting, challenging, and fascinating of what has generally been a very interesting and challenging federal service career. I have been assigned to the Office of the Secretary of Defense continuously these last 12 years—first as an Air Force officer and since 1975 as a civil servant—and I have been privileged to witness, and in some instances participate in, what I believe are some fairly important transformations in Defense thinking, planning processes, and—most importantly—in existing and programmed Defense capabilities.

Things have really changed in the Office of the Secretary of Defense and DoD during the last decade. I would like to sketch out for you—from the OSD perspective—the changes that have occurred in several different aspects of Defense logistics planning and management. I write as an active, often frustrated, occasionally satisfied, participant in the process. The seven facets of Defense planning and management that I will touch on are these:

EVOLVING ASPECTS OF DEFENSE LOGISTICS PLANNING AND MANAGEMENT

• OSD Activism	• Analytical Capability
• The PPB Process	• OSD Logistics Management and Policy Focus
• Priorities for Materiel Readiness	• Concerns for Readiness from Outside DOD
• Sustainability	

Figure 1

Obviously, these seven facets of Defense planning and management are not mutually exclusive but are highly interrelated. For example, certain changes in the PPB process, coupled with improvements in our support analysis capability, made it possible for OSD to become more active and have more impact in establishing logistics program objectives and seeing that the necessary resources are allocated to move toward those objectives. I hope that as I discuss the evolution in each of these areas, the interactions among them will be more obvious. If I can do an adequate job of describing the evolutions along these seven parallel paths, I think I will have given you some understanding of the fundamental changes in Defense logistics planning and programming during the last decade.

After this historical survey, I will give you a few thoughts about what we are likely to face during the 1980s.

OSD Activism

First, a few words on the evolution of the OSD activism in Defense planning and resource allocation. Most of you will remember that the Kennedy Administration included Robert McNamara as Secretary of Defense. McNamara—having read and been greatly influenced by Hitch and McKean's *Economics of Defense in the Nuclear Age*—directed the creation of a planning, programming, and budgeting system for the Department of Defense. The novelty here was the programming feature. We obviously had had plans and budgets for many years. However, the two were largely unrelated and the PPB process was an attempt to bring planning and resource allocation into consistency. Along with creation of the DoD PPB system, Secretary McNamara established an Assistant Secretary of Defense for Systems Analysis, the first incumbent being Alain Enthoven who brought together the group that was soon dubbed the Pentagon "whiz kids." You may also remember they were generally either despised or held in awe, depending on where you sat. Thus, during the 1960s, a strong-willed Secretary of Defense with an equally strong analytical staff began to grapple analytically with the links among threat, strategic objectives, and force structure requirements. However, during that decade OSD gave limited consideration to logistics support except for war reserve authorizations. My impression was that the OSD analysts—at least in the Systems Analysis office—behaved as if there were some well-defined, automatic, and inflexible relationship between combat forces and their support requirements so that all one needed to do was to size the combat force structure, with complete confidence that the required support capability would automatically be provided.

As the Nixon Administration took the Defense helm in 1969 and the early 1970s, much of the initiative for force planning reverted from OSD back to the Military Departments; however, about the same time, there began to emerge within OSD an output-oriented, activist concern for logistics support and readiness. During the last decade there has been an increasingly strong attempt by OSD to ensure that the combat force structure is provided balanced logistics support capability. That is, there has been an attempt to ensure that enough munitions and spares procurement and maintenance funding is programmed to provide a level of materiel readiness that is appropriate for our strategic planning assumptions.

To sum up my comments on the evolution of OSD activism in Defense planning, we might think of the 1960s as the decade of OSD involvement in Defense force planning, and the 1970s as the decade when OSD became a major influence on logistics support programs and the materiel readiness they produce. How this increased OSD concern for materiel readiness has been translated into adjustments to the Defense program should be clearer once I have traced the transition in the other areas on my menu.

The PPB Process

Let me now touch briefly on developments in DoD's planning, programming, and budgeting process—the mechanism through which this OSD activism could operate. During the McNamara years the Office of the Secretary of Defense came to publish a series of force structure sizing documents—referred to as Draft Presidential Memoranda—and other related program guidance documents. One of these was called the logistics guidance. The annual logistics guidance authorized certain war reserve inventory objectives for the upcoming budget year. These two key characteristics are significant: (1) it was an *authorization* only; that is, it lacked provisions to ensure that the Services actually allocated enough money in their budget requests to attain those objectives; and (2) it had a one year planning horizon. The result was that war reserve procurement enjoyed more philosophy and rhetoric than funding.

The new planning, programming, and budgeting system included a Five-Year Defense Program data base—or

FYDP—that documented the approved program at any point in time. However, the four out-years of this FYDP were not constrained to anyone's realistic expectation of out-year Defense Department budget levels. In other words, there was a tremendous bow wave in the program. Thus, through the 60s we had a situation where the Services would submit to OSD a budget request that was consistent with the then-approved—but generally fiscally unrealistic FYDP—whereupon OSD Systems Analysis and the Comptroller would whack that budget request down to the figure that the Secretary of Defense thought he could sell to the President, and he in turn to the Congress.

The Service Chiefs complained—with considerable justification—that most of the key decisions on the Defense program were being made in OSD during this budget preparation. They argued that they should be given the best available information on the resource levels that were likely to be available during the budget and program years and the initiative to construct a Defense program within those resource levels.

When the Nixon Administration took office and Melvin Laird became Secretary of Defense, he heeded the pleas of the Service Chiefs. Beginning in 1970 for the FY 72-76 program development, the Secretary of Defense issued five-year fiscal guidance to each of the Military Departments and asked them to recommend a Defense program for their Department within those fiscal constraints. The Secretary of Defense also provided specific additional guidance that described the kinds of military capabilities we should be able to provide in the various theaters of interest. The crucial element in this fundamental change in the PPB process—at least from the logistician's perspective—was a completely new and different kind of five-year logistics guidance for program development. That guidance enunciated the principle that we should attempt to balance force levels, modernization, and logistics support within the specified fiscal constraints. That might read like motherhood for how could any reasonable man disagree? We found, in fact balanced forces and logistics support capability in principle fought like tigers when OSD proposed to force them to actually spend significant amounts of their scarce resources to provide that support. However, the general principle survived. For the first few PPS cycles under the new system, this logistics guidance focused largely on war reserve procurement, particularly munitions, and on sizing and modernization of the complementary industrial production base. A couple of years later the OSD campaign expanded into the maintenance and supply areas. Program and budget issues were raised in calendar years 1973, 74, and 75, that led the Secretary of Defense to add several hundreds of millions of dollars to the service programs and budgets for ship maintenance, aircraft and ship spares procurement, and component repair.

To sum up, we now have a planning, programming, and budgeting system within which the Office of the Secretary of Defense provides five-year fiscal guidance to each of the Military Departments, also describes the type of military capabilities that we are to provide in each of the theaters of interests, and then directs the Services to program the funds necessary to provide a properly balanced logistics support capability, in some cases by specific points in time. The OSD staff, of course, reviews the Service program proposals that are forwarded in response to the OSD guidance and raises issues on deviations from that guidance for resolution by the Secretary. Thus, the current PPB system does provide a mechanism through which the Secretary of Defense can define his standards for logistics support adequacy and—if he wishes—ensure that the Services program the resources to meet them.

Higher Priorities for Materiel Readiness

So far I have emphasized the increasing OSD activism in logistics support planning and the process through which DoD programs and budgets can now reflect that activism. Now let me explore further what led OSD—and ultimately DoD—to the conviction that Defense "materiel readiness" demanded a higher priority than it had previously received in Defense resource allocation.

Although we in Defense generally have some technical definitions of "materiel readiness," permit me to define it here as the "prevailing, day-to-day operational availability of a combat weapon system or systems." The level of this "materiel readiness" is largely determined by inherent reliability and maintainabilty, the availability of spare components and repair parts in the right places at the right times, adequately skilled maintenance manning, functioning test equipment, appropriate technical documentation, and in some cases adequate depot maintenance funding for such things as ship overhauls.

Beginning in the early 1970s, we in Defense recognized some serious materiel readiness deficiencies. The poor materiel condition of the Navy fleet and the large number of ships overdue for overhaul were particular concerns. These specific problems were largely the result of competing resource demands during the Vietnam war and the conscious decision by the Navy after the war to accord first priority to fleet modernization rather than improved readiness.

However, this same sense of priorities was pervasive throughout Defense: The traditional focus in Defense planning had been on maintaining adequate force levels and on modernization of those forces, with the implicit assumption that any readiness deficiencies could and would be corrected by a massive infusion of resources in time of crisis. There was frequent mention of the admittedly long procurement lead times on major weapon systems and how that "obviously" meant we should spend our money first on these items with the longest lead times.

Now, it was—and is—certainly true that our 24-month aircraft procurement lead times are significantly longer than the time required to expand munitions production. It is also true that we can probably run the entire Navy fleet through an overhaul cycle in the time required to build a single aircraft carrier. However, we concluded after a little reflection that these differential lead time arguments were really irrelevant so long as the strategic warning that we could safely anticipate of a future major conflict was much shorter than any of them. In other words, if we can only count on a few days or weeks of strategic warning of an impending conflict we must worry about the 6-*month* as well as the 6-*year* leadtime problems. Over the last seven or eight years this thinking has become more and more widely accepted within the Department of Defense, with the result that a serious concern for readiness is being reflected in DoD programs and budgets.

In large measure as a result of this rethinking, beginning in the mid-1970s there were substantial increases in ship maintenance program funding. The results can be seen in a steadily improving materiel condition of the fleet, and in a reduction in the number of ships overdue for overhaul from 68 at the end of FY 1976 to a projected 14 at the end of FY 1981.

Another more recent and dramatic illustration of this reordering of Defense priorities towards materiel readiness can be seen in the fact that the Air Force's FY 1982 aircraft spares procurement budget is well over a billion dollars higher than in FY 1981. Furthermore, the Air Force spares procurement that programmed for fiscal years 1982, 83, and 84, is about $600-700 million per year higher than was programmed for those same years as recently as January 1980.

Sustainability:

In contrast to the big OSD push for improved materiel readiness—our prevailing, day-to-day ability to respond to an emergency—the OSD scrutiny of the combat *sustainability* issue has taken a somewhat different turn. Combat materiel sustainability—the ability to supply replacement munitions and equipment in wartime—is closely related to our industrial preparedness. Granted industrial preparedness is just one key element of sustainability, the other is our war reserve stock of equipment, munitions, and spares. The fundamental issue of sustainability—that is, the conflict duration for which Defense should design its forces, and size its support resources—has in some ways been a more contentious issue than materiel readiness. We still lack complete consensus within the Department of Defense regarding the appropriate level of combat sustainability toward which we should aspire. Furthermore, there has been substantial disagreement about the relevance of U.S. Defense industrial preparedness to the kinds of scenarios for which we must be prepared.

The world has changed since Korea—certainly since World War II—in some ways that have inevitably led to our rethinking the utility of, and our approach to, Defense industrial preparedness.

Vastly increased weapon system sophistication and complexity have had a major impact on the production base capacity and responsiveness that we can acquire at an affordable cost. To illustrate, let us say that one turns the clock back and defines as a baseline the set of production facilities, capital equipment, subcontractor capacities, network of subordinate vendors, etc., that could produce five F-15s per month in peacetime most efficiently. By definition, he would have a base with little slack capacity and limited acceleration capability. If he then said that he wanted the capability to accelerate production from five per month to 25 per month within 12 months from decision, I think we could demonstrate fairly quickly that the cheapest solution would still entail a substantial incremental cost above the baseline.

I further submit that, even if we were willing to pay the financial costs of a highly responsive production base—with substantial peacetime slack capacity—we would still confront a planning, management, and information handling task of staggering proportions. I do not think it is an exaggeration to say that the task would be at least as complex as our effort that put a man on the moon. In some important ways the industrial mobilization planning problem in todays high technology world is probably much more complicated than that space program, because the managers of our space program at least knew precisely what they were trying to do. In contrast, we still spend a lot of our time in the mobilization planning world arguing about just that.

Let me also acknowledge that we obviously have some surge capability in our aircraft production base, to the extent that we are producing—largely because of budget constraints—several aircraft at rates well below those for which we provided the facilities. But, I am sure we would agree that *that* slack capacity and expansion potential is largely an accident—some would say a highly undesirable accident—and not the product of any rational, coherent plan!

But let me get back on the subject. On the one hand, technology is reducing the production base acceleration capability that it is economically attractive to acquire and maintain. At the same time, similar technology advances have vastly compressed the time within which conflict can break out, expand, and possibly proceed to a decisive outcome.

Furthermore, that same technology explosion means that the price-tag on a week's worth of combat attrition replacement equipment for an Army division is enormous. We have, for several years, followed a policy of not even attempting to buy war reserves—that is, combat attrition replacement—aircraft. Our logic has been that the cost to acquire the primary weapon system was such a large fraction of the total life-cycle-cost of, for example, an Air Force tac fighter wing, that we should normally put that aircraft in an organized unit, hire the necessary pilots and maintainers, and thus be in a position to employ its combat potential from D-Day, rather than buying and reserving such an expensive aircraft for an attrition filler.

The cost of land force combat equipment—for example, two-million-dollar-tanks—seems to be moving us inexorably toward the practice of providing little or no war reserve equipment. Now, we in MRA&L think this practice is unwise and resist the trend as best we can; no one has *yet* proposed a *formal policy* of no war reserve equipment; however, the trend in recent program decisions is clear.

Similarly, increased munitions sophistication, effectiveness, and cost have dramatically increased the cost of a week's worth of consumption for an artillery battery. In summary, the cost of buying a week's worth of sustainability continues to rise dramatically.

The combination of the above factors means that:

- while cost makes us more and more penurious about the conflict duration for which we are willing to buy war reserves;
- technological complexity—and other, in some cases possibly more controllable; factors—is stretching out production base response times, with the *result* that
- the time gap between the likely exhaustion of our war reserves, and the point when we can expect expanded output from our production base, continues to widen, and
- investments in industrial mobilization capability purely to support a *major conflict scenario,* have come to seem less and less attractive.

These phenomena largely reflect the interaction of physics and finance. Unfortunately, international politics and strategy reinforce the pressures that made significant investments to improve industrial mobilization capability less appealing. Over the past decade our NATO Allies' clear and continuing disinterest in buying substantial conventional sustainability—presumably for fear, in their view, of undermining the West's strategic nuclear deterrent—has acted as a very real and effective brake on any enthusiasm that might otherwise be generated within the U.S. DoD for a major effort to increase our industrial mobilization capability for *war.*

The end point of the above chain of logic is that many of us have concluded that it is difficult to justify rationally and analytically a major industrial preparedness program on the basis of the *specific conflict* scenarios (and I emphasize *conflict*) that must remain central to our force and support planning.

This story is one of those—like so many in the *real world*—that does not have a happy ending: our logic and analyses have left us with the conclusion that we cannot justify major investments in industrial preparedness, purely on the basis of the contribution the production base could make in our key conflict scenarios. The current Defense program reflects this conclusion. However, many of us in OSD and elsewhere in DoD are uncomfortable with this result. The new Administration is rightly determined to revitalize the U.S. defense industrial base. Thus, the evolution of rational new objectives, policy, and programming criteria for defense industrial preparedness is a major item of unfinished business for the 1980s.

Analytical Capability:

In the two foregoing discussions of the changing emphases on materiel readiness and sustainability—particularly industrial preparedness—I have touched on the two major

logistics policy and program issues with substantial impact on our combat capability. As I attempt to analyze the reasons for any success OSD may have enjoyed in contributing to more rational resource allocation decisions, I see these five major ingredients:

- First, we have been fortunate enough to have some *logisticians* who were, first and foremost, sound *logicians.* They first took a macro look at the implications of some of our policies and programming assumtions. An example was the fairly straightforward assessment that, if we can only anticipate a few days or weeks of strategic warning, we must confront both our six-year lead-time problems and our six-month lead-time problems rather than ignore the latter in favor of the former.
- Second was the fundamental change in the PPB mechanism that introduced reasonably realistic five-year fiscal guidance, coupled with explicit logistics program guidance specifying verifiable support objectives to be met by dates certain.
- Third, continually improved analytical tools.
- Fourth, a marriage of good analysts with good analytical tools, positioned organizationally where they could provide input to the resource allocation process and—extremely important—with the ability to communicate the results of the analyses, formulate issues, and frame recommendations concisely, lucidly, and persuasively; and
- Fifth, perseverance and continuity.

Let me expand a little on the evolution of our ability to define, measure, and analyze materiel readiness. Earlier I referred to "materiel readiness" in terms of the prevailing, day-to-day operational availability of our combat weapon systems. Although this hardware availability idea is not the ultimate output measure, it is far closer to a combat output measure than might be some measure of logistics support performance, such as maintenance backlogs or supply system fill rates. Before discussing our aspirations for better output measures let us examine materiel readiness in general.

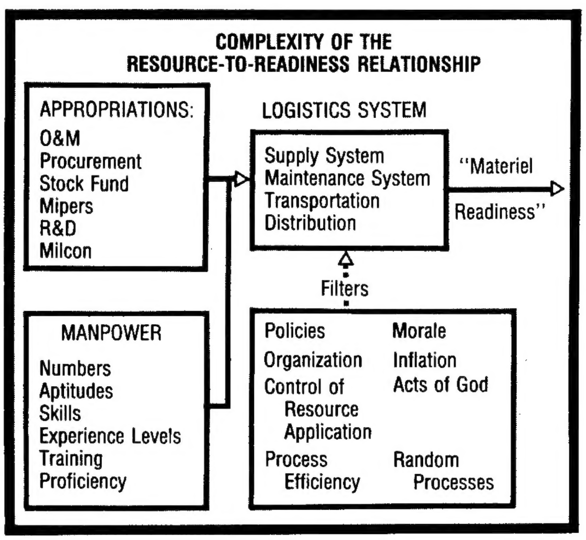

Figure 2

Figure 1 illustrates the complexity of the relationship between resource inputs and materiel readiness resulting. Notice that I have portrayed resource inputs at a highly aggregated level. The attributes of the manpower input are obviously far more difficult to quantify than are the dollars in the budget appropriations. Furthermore, there are numerous interactions between the two major categories of resource inputs—money and manpower. Please ignore all those complexities and look at the fact that there are several different budget appropriations that to a very complex logistics support system, which delivers some level of materiel readiness.

Note also that numerous variables, which one of my colleagues has chosen to call "filters," have a major influence on the relationship between resource inputs and the materiel readiness produced by the system. In the "filter box," note that the first five variables are endogenous to the system and thus presumably within the power of DoD to influence—at least in theory. The last three variables are exogenous variables—that is, completely beyond our power to control.

KEY CENTRALLY-MANAGED FUND INFUSIONS IMPACTING ON MATERIEL READINESS

- Reliability and Maintainability (R&M) Modifications
  - Procurement
  - Installation
- Procurement of Spare Components
  - Initial Support of New Weapon Systems
  - Replenishment (Follow-On) Peacetime Support
  - (And War Reserves to Support Higher Wartime Activity Levels - i.e., For Sustainability)
- Depot Level Maintenance
  - Overhaul, Repair, Modification
  - Engine Overhaul, Repair, Modification
  - Component Repair

Figure 3

In figure 2 I have moved to the next level of detail in describing key resource inputs, to highlight those logistics support programs on which we in OSD have tended to concentrate in trying to ensure that the Defense budget and program contain adequate resources to produce an appropriate level of materiel readiness. Note that rather than presenting these inputs by budget appropriation this figure has a more functional flavor: when we review R&M modification programs, we must consider both the procurement funds with which to buy the modification kit, and the O&M funding needed for installation.

Procurement of spare parts can address several different purposes: initial outfitting for new weapon systems, follow-on spares support for peacetime operations, or procurement to provide the additional increment of spares inventory to support the higher wartime activity levels. One major program funded within the O&M appropriation is depot-level maintenance. That depot-level maintenance program includes the three major subdivisions portrayed here.

Our approach to linking resources analytically to readiness has already progressed through a couple of stages with a third on the horizon. When we first began mucking around in the materiel readiness business we lacked even crude tools to relate resource inputs explicitly to any measure of materiel readiness output. In those days, the mid-70s, we merely laid out the logic of the logistics support system to identify the specific support programs that drive materiel readiness—in other words, maintenance, spare parts procurement, and R&M modification programs. We then examined the existing Service methodologies for computing funding requirements for each of these programs. We addressed our issues in terms of the proposed funding relative to the computed funding requirement as validated—or in some cases, modified—by OSD.

That turned out to be a pretty effective starting place and we even won a few important arguments using this approach—notably on the Navy ship overhaul program. However, we had ambitions to take the next step—that is, to acquire the capability to link resource inputs to an estimate of the equipment availability. The Air Force has pioneered some key research efforts here, working initially with the Logistics Management Institute—with us cheering from the sidelines, and occasionally contributing a little research money. The Air Force can now estimate average aircraft availability, by aircraft type, as a function of spares procurement and depot-level component repair funding. This capability has been particularly valuable in helping the Air Force prepare—and OSD review—its recent five-year program proposals. It has not only been useful in helping set support funding levels, but in helping resolve some issues over the proper balance between spares procurement and depot-level component repair funding.

Estimating weapon system availability on the basis of varying resource input levels is obviously much more useful than merely measuring inputs. But—as I mentioned earlier—we have aspirations to get more meaningful combat output measures than just weapons system availability. In the case of aircraft, both we and the Air Force are sponsoring some research that is attempting to project wartime sortie generation capability over time, as a function of support resources available. In my office, we are also sponsoring some research at the Rand Corporation that is attempting to develop an analogous capability for land forces. These two concepts are illustrated in figure 3.

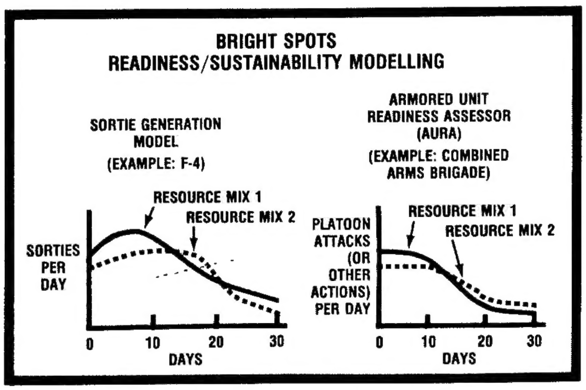

Figure 4

To wind up this thread, we have pretty good analytical tools in several areas and even better ones on the drawing board. My illustrations have drawn on the Air Force; that is by way of example to this readership not because the other Services are not doing relevant, and useful analytical work.

Shifts in OSD Logistics Management Focus

Permit me to mention explicitly the shift in OSD's logistics policy and management focus, most of which has been implied by the points I have already made. As you have probably guessed, over the past few years we in OSD have shifted our focus on logistics management from a purely functional orientation to one that worries more about outputs. For years the OSD Comptroller and other interested OSD offices such as Installations and Logistics (one of the two ancestors of the current MRA&L office) have reviewed, and often cut, logistics support budgets. However, up until the mid-70s, the primary focus was on assessing the efficiency of certain support functions and programs—such as depot maintenance or spares procurement—with virtually no attempt to understand and describe the materiel readiness implications of program proposals or adjustments thereto. I think I'm pretty safe in saying that an OSD-inspired increase was very, very rare.

As you can see from what I have said earlier, a major change in emphasis has occurred over the last few years: while we still set policy and manage by function, we are now far more concerned with combat readiness output implications. I think (and hope) that we are moving toward the day when our weapon system spares support programs will be managed and executed toward specific combat readiness objectives.

Beginning in the mid-70s, OSD greatly increased its attention to maintenance policy issues—that is, issues that concern the fundamental concepts by which we design scheduled maintenance and inspection programs. One product of this shift in OSD emphasis has been a highly successful research and development effort by the Navy that is designing new, far more rational, effective, and efficient surface ship maintenance strategies. Although OSD provided the initial impetus, the Navy has carried the ball entirely on this extremely ambitious and complex effort that seems certain to have a major and positive impact on Navy ship maintenance in years to come.

Concerns for Readiness from Outside DoD

Our crusades for increased readiness-related funding within the Pentagon soon led us to beat the "readiness drum" in defending the DoD budget on the Hill. Though essential, that crusade caused us some difficulties: We quickly generated intense Congressional interest and a voracious appetite for information on the subject. We were presented with these words in the FY 1978 Defense Authorization Act:

FY 1978 DEFENSE AUTHORIZATION ACT (PUBLIC LAW 95-79)

"The Secretary of Defense shall submit . . . quantifiable and measurable materiel readiness requirements for the Armed Forces [and the] readiness status of the Armed Forces . . .

The budget submitted to Congress shall include data projecting the effect of appropriations requested for materiel readiness requirements".

Figure 5

This paragraph actually told us to do something we really did not know how to do, but it's been very inspirational. The next year the Committee report on the Authorization Bill contained this further demand for information relating resources to readiness.

You readers are aware that the Congressional concern about readiness has certainly not abated—if anything, the concern has intensified. You will also remember that in the debate on the Salt II Treaty, several Senators stated that their support would be contingent on increased spending on U.S. military readiness. The Evening News, and programs such as "60 Minutes" and "20/20" aired concerns about our military readiness, often with Congressmen playing prominent roles. About a year ago, the Washington Post ran a series of articles about the readiness of our first-line tactical aircraft. Much was written and much concern expressed over military readiness as it may have been manifested in the aborted rescue attempt in Iran. The New York Times carried a similar series. The FY 1981 Defense Authorization Bill contains a continuing provision that will require DoD to—among other things—project the readiness to be obtained during the budget year based on the funding proposed in the President's budget. That report requirement is outlined here:

SASC REPORT ON THE FY 1979 AUTHORIZATION BILL (SASC REPORT NO. 95-826; MAY 15, 1978)

REQUESTED DETAILED MATERIEL READINESS DATA ON SPECIFIC PROGRAMS (S-3A, F-14, F-15, A-10, AH-1S, OV-1, AND AV8A)

- ▶ All Materiel Readiness Criteria
- ▶ FY 74-78 Trends in Criteria
- ▶ Contributions to Cirteria (e.g., Spares, Repair of Reparables, etc.)
- ▶ Budget Accounts That Contribute to Materiel Readiness
- ▶ FY 75-80 Funding in Identified Budget Accounts
- ▶ Explanation of Trends in Readiness Criteria

Figure 6

Paralleling the DoD, Congressional, and media interest in readiness, there has been an intensification of interest by OMB. Defense readiness was also a significant issue in the recent Presidential campaign. Although there are obviously days when we hate all this attention, particularly the occasional requests for information that we really do not know how to generate, on balance I would have to say I think it is healthy.

We should be focusing more on the true combat potential that our Defense budget buys than we did in past decades.

That brings me to what I see in the future: In those all-too-infrequent instances when I'm able to ignore todays alligators long enough to survey the depth of the swamp we hope to drain tomorrow, I am forced to conclude that *a* — if not *the* — major challenge of the 1980s to all of us in Defense will be to provide adequate day-to-day military readiness (in some dimensions an inherently perishable commodity) in an increasingly difficult environment. That environment now seems certain to present increasing threats to U.S. world interests that will demand continuing qualitative and quantitative improvements in our combat forces; thus, we will inevitably see increasing sophistication and complexity in the systems we field—whether we logisticians like it or not.

FY 81 DEFENSE AUTHORIZATION ACT TITLE X - GENERAL PROVISIONS

REPORT TO CONGRESS BY FEB 15 OF EACH FY ON NEXT FY BUDGET

- ▷ Aircraft Flying Hours
- ▷ Ship Steaming Hours
- ▷ Field Training Days
- ▷ Number of Ship Overhauls (For Ships Over 3,000 Tons)
- ▷ Number of Airframe Reworks
- ▷ Number of Vehicle Overhauls
- ▷ Justifications for Funding Proposed for All of Above
- ▷ Project C-Ratings
  - ▶ Overall
  - ▶ Equipment & Supplies On-Hand
  - ▶ Equipment Readiness
  - ▶ Personnel
  - ▶ Training
  - ▶ Divisions
  - ▶ Brigades
  - ▶ Regiments
  - ▶ Wings
  - ▶ Squadrons
  - ▶ Ships

Figure 7

We will face an increasingly tight military-aged manpower supply. At the same time, technological trends will bring a larger fraction of our force into close contact with sophisticated hardware, either as operators or maintainers, thereby placing an additional premium on our ability to attract and retain people with the essential technical aptitudes. We will face all of these changes in an atmosphere of increasingly stiff competition for national resources, rising energy costs, and the necessity to pay the significant additional personnel costs necessary to keep the all volunteer force working. Thus, we are entering a decade where adequate military readiness will be ever more essential while the competition for the requisite resources to provide it is even more severe.

This situation dictates that we have still better measures of readiness, improved visibility of the allocation and application of those resources that influence that readiness, more faithful and credible analytical tools, and a renewed determination to present the strongest possible case for adequate readiness with the clearest possible illumination of the resources required to provide it. The ball is in your court.

Most Significant Article Award

The Editorial Advisory Board has selected "A Rendezvous Building with the Soviet Union" by General Bryce Poe II, USAF, Retired, and "Impact of the Comprehensive Engine Management System on Air Force Aircraft Maintenance Organizations" by Capt Daniel J. Somers, USAF, as the most significant article in the Summer 1981 issue. In cases like this of a tie vote, both authors receive awards.

USAF LOGISTICS POLICY INSIGHT

Civil Reserve Air fleet Clarified.

In January of this year the Air Force revised its approach to the Civil Reserve Air Fleet (CRAF) Enhancement Program. This program is designed to add cargo-convertibility features to U.S. wide-body passenger aircraft. Since June of 1978 attention has been focused on adding these features during the initial production process. This remains the preferred method, but in the current economic environment, the airlines have delayed indefinitely their plans to buy new wide-body passenger aircraft. As a result the Air Force notified Congress that a dual approach was needed to improve the ability of the nation's civil air carriers to provide cargo airlift augmentation. In the near term, existing aircraft will be modified and when the airlines again begin buying new wide-body passenger aircraft, the new production method will continue. The retrofit program was launched on 22 Apr 81 when MAC issued a Request for Proposal (RFP) to all potential participants. Technical responses to this RFP were received on 30 June 81 and 125 aircraft were offered. Contracts awarded from this solicitation will be under the "Multiyear Contracting" method and will go to the responses that offer the lowest cost per unit of added military cargo capability. MAC expects to award the contracts in September or October of this year.

Logistics Checkmate Results Studied.

Logistics CHECKMATE (WINTER 1980, *Air Force Journal of Logistics*) has conducted an analysis of operational plans and potential scenarios for the Rapid Deployment Force in Southwest Asia. The analysis identified many new requirements that must be satisfied if the Air Force would be required to deploy to and conduct operations in the desert environment found in the Arabian Gulf region. The requirements have resulted in significant new concepts and initiatives that must be developed due to the lack of infrastructure found in the region. The concepts and initiatives are resulting in major funding programs in the Air Force budget. When all actions are realized, they will greatly enhance Air Force readiness to defend our interests in that important region.

USAF Energy Conservation and Management Set.

AFR 18-1 was recently revised to include additional guidance on energy conservation and management. The energy conservation awareness program was greatly expanded. This program named "Project: Save Energy" is designed to encourage Air Force personnel to conserve energy both on the job and at home. The first phase of this program is "Energy Awareness Week" scheduled for 25-31 Oct 1981. The theme for that week will be "Energy Efficiency in all Operations."

The NATO Mutual Support Act Clarified

The NATO Mutual Support Act (Public Law 96-323) signed into law in August 1980 will enable the USAF to enter into reciprocal logistics support arrangements with NATO allied forces and subsidiary organizations of NATO. Prior to this legislation, the U.S. could only transfer supplies and services to NATO allies through foreign military sales procedures. Additionally, the U.S. could only acquire supplies and services from NATO allies through contracts drawn up under the Defense Acquisition Regulation procedures. Our NATO partners objected to several of the provisions contained in these type contracts. The new legislation will permit transfer and acquisition of supplies and services on a reimbursable or a replacement-in-kind basis and also will waive objectional provisions of contracts. The NATO Mutual Support Act will be implemented by Air Force Regulation 400-9, to be published in September 1981.

"A Preliminary Investigation of the Life Cycle Costs of a Digital Processor Using Very High Speed Integrated Circuits"

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Introduction

The military services are hungry for faster, more reliable processing of data whether it occurs aboard airplanes, ships, or on the ground. Whereas current processing rates of 1 to 10 million instructions per second (Mips) are currently attainable by systems such as airborne radar processors, spread spectrum communication processors, and wideband data links, these same systems will require processing rates of 100 to 10,000 Mips in the next generation implementations. (1) A six-year DOD technology program, called the Very High Speed Integrated Circuit (VHSIC) program, has been implemented in hopes of satisfying this need. The VHSIC program is designed not only to increase the speed of electronic processing, but also to lower costs of military electronic systems. It is the purpose of this article to investigate costs associated with VHSIC technology.

The approach taken is to describe a typical avionics system (in this case a synthetic aperture radar processor), and then obtain life cycle costs of implementation of this system for various values of VHSIC memory chip size; several types of chip technology such as MOS, bipolar, SOS substrates, etc.; the degree to which computer-aided-design methods are used in the chip design process; and the degree to which on-line testing and repair is implemented in systems using VHSIC chips.

The VHSIC program is a tri-service DOD program designed to produce integrated circuit technology (including example integrated circuits) directly useful to future military electronic projects. It is a multi-phased program with phases 0, 1, and 2 occurring sequentially, and the last phase (phase 3) occurring concurrently with phases 0, 1, and 2. (2) Phase 0 is the VHSIC program definition phase which ended December, 1980. Phases 1 and 2 are the implementation phases. The requirements for phase 2 are more demanding than those of phase 1. Phase 2 will end by 1986. The major technical requirements for VHSIC chips are shown in Table I. (3)

The life cycle cost model presented here is based upon the following general scenario. Consider an aircraft digital avionics system which undergoes three major phases in its life cycle: development, acquisition, and deployment.

During development three primary activities occur. First, the system is designed. Second, as a part of system design, VHSIC chips are designed, fabricated, tested, and used to implement the third primary activity which is to assemble and checkout one or more brassboard implementations of the system.

In the acquisition phase, the system design is finalized, several preproduction systems are built and tested, and the production of all deployed systems is carried out. For cost purposes, all systems produced during the acquisition phase have the same fabrication cost.

REQUIREMENT	*PHASE 1*	*PHASE 2*
Clock rate	30 MHz	100 MHz
Feature size	1.25 m	0.5 m
Static RAM size	64 Kbits	256 Kbits
MILSPEC performance	Required	Required
Figure-of-merit	10^{11}gates-Hz/CM^2	10^{13}gates-Hz/cm^2
Radiation Hardening	To man-surviveable	To man-surviveable
Fault-tolerance	Required	Required
Built-in-test	Required	Required
Failure rate	0.6%/1000 hrs @125° C amb.	0.1%/1000 hrs @ 125° C amb.

Table I. Basic Requirements of the VHSIC Program.

Finally, in the logistics phase all consumables used for the life of the program are purchased at the beginning of the logistics phase. The logistics scenario centers around printed circuit boards as the basic repairable units. A three-level logistics base is assumed (depot, base, and on-line repair). In essence, the model used for logistics costs is a standard one (4). Fortunately, this logistics cost model is robust enough to accommodate systems incorporating VHSIC chips.

DEVELOPMENT COSTS

$$\text{Development costs} = \sum_{i=1}^{3} DC_i$$

where DC_1 = Total cost of system hardware design, fabrication, and test.
DC_2 = Total cost of integrated circuit design, fabrication, and test.
DC_3 = Total cost of software support, design, code, and test.

SYSTEM DEVELOPMENT COSTS (DC_1)

DC_1 = CSD + CBB + CST + CSO
where CSD = Total cost of system design labor.
CBB = Total cost of system brassboard component design, fabrication, and test.
CST = Total cost of system test design.
CSO = Total cost of system development management and documentation.

We further define CBB to be:

$$CBB = \left\{ ND \sum_{i=1}^{NB} [CPCD_i + \sum_{j=1}^{NT_i} CFC1_j \cdot N_{ij}] + CD \right\}$$

where ND = Total number of brassboard systems to be built. Each brassboard system is assumed to cost the same.
NB = Number of printed circuit or wirewrap boards in a brassboard system.
NT_i = Number of integrated circuit types on board i.
$CPCD_i$ = Cost to design and fabricate the ith printed circuit (or wirewrap) board. This cost does not include components such as integrated circuits, resistors, capacitors, etc., to be mounted on each board.
CD = Total cost of all brassboard chassis, backplanes, connectors, power supplies, etc.
$CFC1_j$ = Cost of fabricating and testing a type j developmental integrated circuit for the brassboard system.*
N_{ij} = Number of integrated circuits of type j on board i.

* An integrated circuit type is an informal designation of its primary function such as a memory chip, control processor chip, signal processor chip, etc.

DEVELOPMENT INTEGRATED CIRCUIT COST (DC_2)

$$DC_2 = \sum_{i=1}^{NTIC} \left\{ \begin{array}{l} (CCD_i + CFC2_i \cdot NPIC_i + CCT_i + CCO_i) \\ \text{or } |CF_i| \text{ if } CF_i \leq 0 \end{array} \right\}$$

where CCD_i = Cost to design integrated circuit chip of type i.
$CFC2_i$ = Cost to fabricate and test a prototype integrated circuit of type i.
CCT_i = Cost to design tests for integrated circuit chip of type i.
CCO_i = Cost of management and documentation for type i integrated circuit chip.
$NPIC_i$ = Number of prototype type i integrated circuit chips to be fabricated.
NTIC = Number of integrated circuit types in each brassboard system.
CF_i = Purchase cost of a type i integrated circuit (if CF_i is a negative value). If CF_i is positive, then the cost of the integrated circuit chip of type i is calculated using the summation equation in DC_2 above.

Software Development Cost (DC_3)

$$DC_3 = DOSC + DSSC$$

where DOSC = Cost of software used operationally by the brassboard system.
DSSC = Support software costs.

Operational and support software costs are further defined as:

$$DOSC = DNOW \cdot DCOL + DCOP$$

where DNOW = Total number of lines of operational code specifically written for the development system. This includes discarded code as the system development evolves.
DCOL = Average cost of operational software per line written.
DCOP = Total cost of purchased software used operationally in the brassboard system.

$$DSSC = DNSW \cdot DCSL + DCSP$$

where DNSW = Total number of lines of support code written for the brassboard system. This includes analysis, simulation, and system software.
DCSL = Average cost of support software per line written.
DCSP = Total cost of purchased support software in support of the brassboard system.

ACQUISITION COSTS

$$\text{Acquisition costs} = \sum_{i=1}^{5} AC_i$$

where AC_1 = Total cost of system hardware design, fabrication, and test during the acquisition phase.
AC_2 = Total cost of all production equipment required to support acquisition activities.
AC_3 = Total cost of all support equipment required during the acquisition phase.
AC_4 = Total cost of all management and technical data required during the acquisition phase.
AC_5 = Total cost of all software support, design, code, and test.

ACQUISITION SYSTEM DESIGN AND FABRICATION COST (AC_1)

$$AC_1 = NS \sum_{i=1}^{NB} [COCB_i = \sum_{j=1}^{NTIC} (CFC_j + CSTF_j) N_{ij}] +$$

$$NS \cdot CC + CDA$$

where NS = Number of systems to be produced in the acquisition phase. This number includes both acquisition test and design units, as well as all the initially deployed units.
$CPCB_i$ = Unstuffed cost of the ith printed circuit board in the system.
NB = Number of printed circuit boards in the system.
CFC_j = Cost of fabricating or purchasing an integrated circuit of type j.
N_{ij} = Number of integrated circuits of type j on the ith printed circuit board.
$CSTF_j$ = Cost of stuffing a type j integrated circuit on a printed circuit board.

CC = Total cost of all chassis, backplanes, connectors, power supplies, and other non-integrated circuit components.
CDA = Cost of design labor during the acquisition phase.

ACQUISITION PRODUCTION EQUIPMENT COST (AC_2)

$$AC_2 = PEC + PEMC$$

where PEC = Cost of all production equipment used to fabricate, test, and exercise the system during the acquisition phase.
PEMC = Cost of all production equipment maintenance.

ACQUISITION SUPPORT EQUIPMENT COST (AC_3)

$$AC_3 = SEC + SEMC$$

where SEC = Cost of all support equipment used during the acquisition phase
SEMC = Cost of all support equipment maintenance.

ACQUISITION MANAGEMENT AND TECHNICAL DATA COST (AC_4)

$$AC_4 = MC + TDC$$

where MC = Cost of acquisition management.
TDC = Cost of technical data generated during the acquisition phase. Design data is *not* included

$$TDC = \sum_{j=1}^{NTIC} DIC_j + \sum_{i=1}^{NB} DPBC_i + SYS$$

where DIC_j = Cost of technical data for integrated circuit of type j.
$DPBC_i$ = Cost of technical data for printed circuit board i.
SYS = Cost of technical data for the system.

SOFTWARE ACQUISITION COST (AC_5)

$$AC_5 = AOSC + ASSC$$

where AOSC = Cost of software used operationally by the acquisition system.
ASSC = Support software costs for the acquisition system.

Operational and support software costs are further defined as:

$$AOSC = ANOW \cdot ACOL + ACOP$$

where ANOW = Total number of operational code specially written for the acquisition system. This includes discarded code as the acquisition system evolves.
ACOL = Average cost of operational software per line written.
ACOP = Total cost of purchased software used operationally in the acquisition system.

$$ASSC = ANSW \cdot ACSL + ACSP$$

where ANSW = Total number of lines of support code written for the acquisition system. This includes analysis, simulation, and system software.
ACSL = Average cost of support software per line written.
ACSP = Total cost of purchased support software in support of the acquisition system.

LOGISTICS COSTS

$$\text{Logistics Cost} = \sum_{i=1}^{7} LC_i$$

where LC_1 = Cost of spare boards
LC_2 = On-equipment maintenance costs
LC_3 = Off-equipment maintenance costs
LC_4 = Inventory management costs
LC_5 = Cost of support equipment
LC_6 = Cost of personnel training
LC_7 = Cost of technical data.

All equations for LC_i except LC_4 and LC_7 are directly obtained from the Logistics Support Cost Model User's Handbook (4). Equations for LC_4 and LC_7 are obtained from West (5). Rather than repeat these equations here, the interested reader is referred to these two references.

The integrated circuit fabrication costs ($CFC1_j$, $CFC2_j$, and CFC_j) are all based on the general integrated circuit process model shown in Figure 1. This is the same model used by Cornell (6) resulting in the cost equations that were used for this study.

Each life cycle phase (development, acquisition, and logistics) incurs a different cost to produce integrated circuits primarily due to differing yields. We choose to consider all integrated circuit costs parameters other than yield the same regardless of the life cycle phase in which they occur.

The avionics system analyzed in this study is an airborne synthetic aperture radar digital processor. This processor is characterized as follows.

Assume the processor requirements are as shown in Table II. The processor receives digital data at high speed from the radar transmitter/receiver unit, converts that data to an image, and displays the image (or part of it) on a CRT in the cockpit.

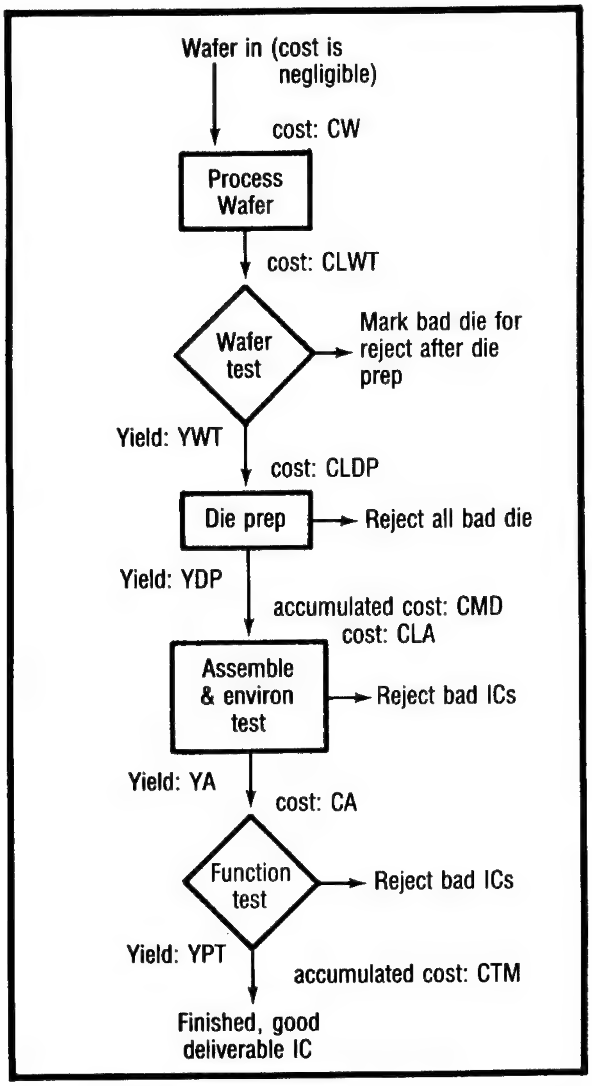

Figure 1. General process model for integrated circuit fabrication. The assembly function includes packaging and lead bonding. The die prep function includes wafer scribe, break, and visual inspection.

ITEM	*REQUIREMENT*
Resolution	5 feet range, 7 feet azimuth
Collection mode	Stripmap
Processing mode	5 nm range by 7nm azimuth in slant plane
Range of radar	50 nm
Altitude of radar	30,000 feet
Speed of processor	Realtime
MTBF of processor	As calculated from the integrated circuit chips and other components in the radar processor

Table II. Requirements for an example SAR processor.

Figure 2 shows the major function in the SAR processor using the polar format method to reduce error affects due to range walk (see Walker (**8**)).

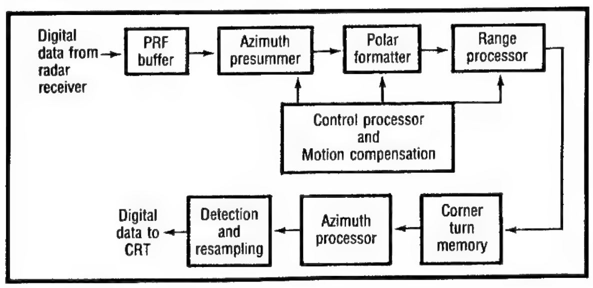

Figure 2. SAR image processing functional diagram

The processor is designed to a level sufficient to get an idea of the number of chips and printed circuit boards in an implementation of a radar processor. (**10**) The results of the design are shown in Table III.

Using Table III along with a derived estimate of the expected chip densities it is possible to get an estimate of the number of VHSIC chips and thus the number of printed circuit boards required to implement the radar processor.

FUNCTION	*MAX OP RATE*	*MEMORY SIZE*	*NO. OF GATES*	*TECHNOLOGY*
PRF Buffer	150 Msps	0.219 Mbits	Very few	Bipolar, SOS, I^2L
Azimuth Presummer	17.9	Negligible	10,000	Bipolar, SOS, I^2L
Polar Formatter	17.9	100 Mbits	16,000	Bipolar, SOS, I^2L (MOS memory)
Range Processor	17.9	Negligible	10,000	Bipolar, SOS, I^2L
Azimuth Buffer Memory	17.9	1660 Mbits	Negligible	MOS
Azimuth Processor	17.9	Negligible	10,000	Bipolar, SOS, I^2L
Image Detection	17.9	Negligible	5,000	Bipolar, SOS, I^2L
Control and Motion compensation proc.	2.0	12 Mbits	100,000	Bipolar, SOS, I^2L MOS

Table III. Speed and gate complexity of a SAR radar processor. I^2L is Injection Current Logic; SOS is Silicon-on-Sapphire.

Assume that chip densities in the VHSIC program for 1.25 um feature size will be as shown in Table IV.*

* See Carter (**10**) for the derivation of these values.

TECHNOLOGY	GATES OR MEMORY CELLS PER SQ. MIL
Logic	
I^2L custom	2.06
I^2L gate array	1.24
Bipolar custom	.52
Bipolar gate array	.31
MOS custom	1.03
MOS gate array	.62
Memory	
ECL	1.0
MOS	0.1

Table IV. Expected densities for 1.25 um VHSIC chips.

Then we can deduce the number of VHSIC chips required to implement the radar processor by partitioning the logic and memory requirements onto chips of appropriate sizes. Consider first the logic requirements from Table III. 51,000 gates of high speed ($\approx$ 20 MHz) are required to implement the signal processor portion of the radar processor. 100,000 gates of slower logic ($\approx$ 5 MHz) are required to implement the control and motion compensation processor (hereafter called the control processor). The logic seems to naturally divide between two chips: a fast signal processor chip, and a slower control processor chip. If approximately 15% of the area of an integrated circuit chip is devoted to non-useable area (e.g., bonding pads, border area, chip test points, etc.) and using the data from Table IV, we obtain the chip sizes as shown in Table V for the signal processor and Table VI for the control processor.

The chip sizes given in Tables V and VI affect chip fabrication yields which in turn affect life cycle costs.

The amount of memory required by the radar processor is quite high: 1762 Mbits in the signal processing part of the radar processor, and 12 Mbits in the control processor. Using the densities in Table IV, Table VII shows the number of memory chips required to implement these memories as a function of chip size. Active memory cell area on each chip is assumed to be 85% of the total chip area.

TECHNOLOGY	CHIP SIZE	SIDE DIMENSION
I^2L custom	29067 mil^2	170.5 mil
I^2L gate array	48433	220.1
Bipolar custom	114882	338.9
Bipolar gate array	193294	439.7
MOS custom	58134	241.1
MOS gate array	96885	311.3

Table V. VHSIC chip size as a function of technology for the signal processor which consists of approximately 51,000 gates. The side dimension is the square root of the chip size.

TECHNOLOGY	CHIP SIZE	SIDE DIMENSION
I^2L custom	56986 mil^2	238.7 mil
I^2L gate array	94975	308.2
Bipolar custom	227941	477.4
Bipolar gate array	379901	616.4
MOS custom	113971	337.6
MOS gate array	189951	435.8

Table VI. VHSIC chip size as a function of technology for the control processor which consists of approximately 100,000 gates. The side dimension is the square root of the chip size.

	MEMORY FOR THE SIGNAL PROC.		MEMORY FOR THE CONTROL PROC.	
CHIP SIZE (mil x mil)	ECL	MOS	ECL	MOS
750 x 750	3686	369	26	3
1000 x 1000	2073	208	15	2

Table VII. Number of memory chips required by the radar processor.

MEMORY CELL SIZE (mil x mil)	*NUMBER OF VHSIC CHIPS ON EACH BOARD*			
	BOARD 1	*BOARD 2*	*BOARD 3*	*BOARD 4*
750 x 750	2 logic, 98 memory	100 memory	100 memory	74 memory
1000 x 1000	2 logic, 98 memory	100 memory	12 memory	Not needed

Table VIII. Quantity and composition of two board mixes as a function of memory chip size.

Obviously, the radar processor is highly memory intensive. It is apparent from Table VII that MOS memory chips is the best candidate for any VHSIC implementation of the radar processor.

By combining the data in Tables V, VI, and VII, we can generate a mix of printed circuit board sets that make up the radar processor. Several assumptions are made: 1) Each board holds 100 integrated circuits, 2) Only MOS memory chips are used, and 3) all integrated circuits are VHSIC. Table VIII shows the two board mixes used in this study.

Another important cost parameter is MTBF. We consider the MTBF of VHSIC chips to be at or above the level established by the Department of Defense in the VHSIC Phase 1 RFP, namely, 0.006 failures per 1000 hours per chip. (9) Thus, the radar processor MTBF is primarily a function of the number of integrated circuits on each board and the number of boards in each radar processor.

Assume a chip carrier has a reliability of 0.01 failures/1000 hours, an unstuffed printed circuit board has a realiability of .001 failures/1000 hours, and the board connector has a reliability of .05 failures/1000 hours. Since the total board reliability is the sum of the reliability of its component parts, we have the board failure rates shown in Table IX. The MTBFs corresponding to these failure rates are shown in Table X.

MEMORY CHIP SIZE	*BOARD* 1	2	3	4
750 x 750 mil	1.651	1.651	1.651	1.235
1000 x 1000	1.651	1.651	0.243	—

Table IX. Failure rate per 1000 operating hours for each board in the radar processor.

MEMORY CHIP SIZE	*BOARD* 1	2	3	4
750 x 750 mil	606 hrs	606	606	810
1000 x 1000	606	606	4115	—

Table X. MTBF for each printed circuit board in the radar processor.

It is interesting to note that if we attribute a failure rate of 1.0 failures/1000 operating hours to the rest of the processor (e.g., cables, chassis, backplane, etc.), the total MTBF for the radar processor is 139 hours if 750 x 750 mil memory chips are used, and 220 hours if 1000 x 1000 mil chips are used.

CHIP DESIGN COSTS

The cost to design integrated circuit chips is dependent upon two primary factors. One factor is whether the layout of a chip is a custom design or a gate array design. Custom chips require more time to layout. The other factor is whether computer-aided-design (CAD) systems are used by the chip designers to assist them in the design and layout of each chip.

The average time in manmonths shown in Table XI is assumed to be required to design an integrated circuit chip using computer-aided-design techniques in varying amounts. The values given in the table are manmonths to design either a 10,000 gate logic circuit, or a 1 Mbit memory chip.

USE OF CAD	*DESIGN METHOD* *CUSTOM*	*GATE ARRAY*
None	18	12
Some	12	6
Extensive	6	3

Table XI. Estimated manmonths to design integrated circuit chips using CAD.

If we further assume a chip designer costs the Air Force $84,000 per year (1981 dollars), and if circuit sizes are used as derived for the radar processor, then Table XII gives the estimated manmonths and dollar costs to design each of the three VHSIC chips for the radar processor.

USE OF CAD	*PROCESSOR CHIPS*				*MEMORY CHIPS*	
	SIGNAL		*CONTROL*		*750 mil*	*1000 mil*
	CUSTOM	*GATE AR.*	*CUSTOM*	*GATE AR.*	*CUSTOM*	*CUSTOM*
None	92/644	61/427	180/1260	120/840	86/602	153/1071
Some	61/427	31/217	120/840	60/420	53/399	102/714
Extensive	31/217	15/105	60/420	30/210	29/203	51/375

Table XII. Manmonths and costs (in $1000s) to design the VHSIC chips for the radar processor. The manmonths are given first in each entry.

On-Line Testability

We take a very simplistic approach to modeling maintainability and testability cost parameters by assuming that the number of failed boards needing base-level shop maintenance varies inversely to the degree of fault coverage by the built-in fault detection and isolation circuitry. Furthermore, we assume that chips can be replaced on a board without removing the board from the aircraft. This capability is currently only a gleam in the eyes of the Air Force. However, as technology in high stress packaging of integrated circuits continues to evolve, this capability should be a reality in the not-too-distant future.

This study does not include software maintenance or changes; however, it is expected that as software changes occur, new chips with changed firmware would be sent to the field for replacement on-line the aircraft.

Applying the life cycle cost model to the several implementations of the radar processor as described above, the following results are obtained.

IMPACT OF MEMORY CHIP SIZE ON THE RADAR PROCESSOR COST

The life cycle costs for the radar processor show a difference of 34.5% between the processor implemented with 750 x 750 mil memory chips and one implemented with 1000 x 1000 mil memory chips. Table XIII gives the actual cost data by phase as well as the total life cycle costs.

This same cost data is graphed in Figure 3 Notice that about 64% of the cost difference is due to differences in the acquisition cost.

It is a bit surprising that the processor with fewer boards (three instead of four) is more expensive in terms of life cycle costs. However, even though the board count is reduced by 33% with a total memory chip reduction from 372 to 210 chips, the cost of each 1000 x 1000 mil memory chip is three times more expensive than a 750 x 750 mil chip (because of much lower fabrication yields). Thus, the cost of each radar processor in the 1000 x 1000 mil memory chip case is about $250,000 whereas each processor costs only about $150,000 if it is implemented with 750 x 750 mil memory chips. Similarly, the cost of boards for the more expensive processor more than offsets the cost of maintaining and procurring fewer boards during the logistics phase. For these reasons, the radar processor implemented with lower yield memory chips has a higher life cycle cost.

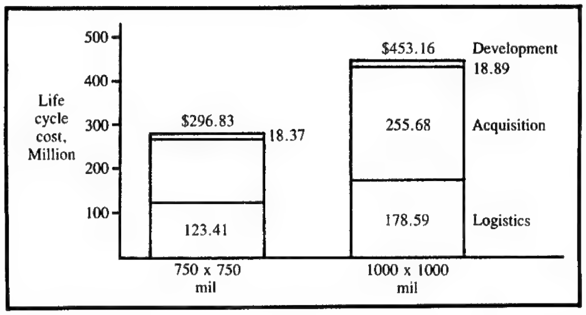

Figure 3 A cost comparison of the radar processor using two sizes of memory chips.

IMPACT OF CHIP TECHNOLOGY ON THE RADAR PROCESSOR COST

The variation of life cycle cost due to signal processor and control processor chip technology is slight (.03%) for the technology mixes examined in this study (see Table XIV). This should not be surprising since of the 374 VHSIC chips in the radar processor, only two of them (i.e., the processor chips) are investigated here with regards to chip technology. The memory chip technology was not investigated due to lack of time and the limitations of the LCC program. In the worst case, the cost of the two processor chips represents only .046% of the total cost of all 374 chips in the radar processor.

If one looks solely at the processor chips, the cost of a gate array chip is about 53% higher than for a custom designed chip for bipolar and MOS chips with between

MEMORY CHIP SIZE	*TOTAL LIFE CYCLE COST*	=	*LOGISTICS COST*	+	*ACQ. COST*	*DEVEL. COST*
750 x 750 mil	$296.83		$123.41		$155.05	$18.37
1000 x 1000 mil	453.16		178.59		255.68	18.89

Table XIII. Life cycle of the radar processor as a function of memory chip size. Costs are in millions of dollars.

CHIP SIGNAL	*TECHNOLOGY CONTROL*	*DESIGN*	*TOTAL LIFE CYCLE COST*	=	*LOGISTICS COST*	+	*ACQ. COST*	*DEVEL. COST*
I^2L	MOS	Custom	$296.83		$123.41		$155.05	$18.37
I^2L	MOS	Gate Array	296.87		123.43		155.07	18.37
Bipolar	MOS	Custom	296.85		123.42		155.06	18.37
Bipolar	MOS	Gate Array	296.94		123.45		155.11	18.38

Table XIV. Life cycle cost of the radar processor as a function of chip technology. Costs are in millions of dollars.

50,000 and 100,000 gates (see Table XV). Interestingly, the 51,000 gate I^2L gate array chip costs only 14% more than the same chip custom designed.

A 51,000 gate bipolar chip costs 57% more than a 51,000 gate I^2L chip if they are both custom designed. The cost increase is 76% if they are both gate-array designed.

TECHNOLOGY	COST PER PROCESSOR CHIP SIGNAL	CONTROL
I^2L custom design	$ 9.95	—
I^2L gate array design	11.53	—
Bipolar custom design	22.91	—
Bipolar gate array	48.33	—
MOS custom design	—	$22.70
MOS gate array design	—	47.14

Table XV. A comparison of processor chip costs.

IMPACT OF WAFER SIZE ON THE RADAR PROCESSOR COST

As shown in Table XVI, wafer size has a profound effect on the life cycle cost of the radar processor. The cost to acquire and support the radar processor implemented with memory chips fabricated from 3″ wafers is 186% higher than with 5″ wafers. 60% of this cost difference occurs in the acquisition phase; 40% in the logistics phase.

IMPACT OF CHIP SUBSTRATE ON THE RADAR PROCESSOR COST

As shown in Table XVII, the use of SOS substrate for all ICs results in a life cycle cost of $654.41 million which is 120% higher than for the same radar processor implemented with bulk silicon chips. 60% of the cost difference is in the acquisition phase; the rest is in the logistics phase.

IMPACT OF CHIP COMPUTER-AIDED-DESIGN ON THE RADAR PROCESSOR COST

The life cycle cost of the radar processor differs by no more than .53% regardless of the use of CAD where the greatest contribution of CAD studied in this analysis shortened the design manhours by a factor of 3 to 1 over that not using CAD at all. Only the signal and control processor chips were analyzed. Memory chips, being of very regular architecture, tends to show little variability in design manhours whether or not CAD is used. Table XVIII shows the life cycle costs of the radar processor as a function of the use of CAD.

WAFER SIZE	TOTAL LIFE CYCLE COST	=	LOGISTICS COST	+	ACQ. COST	+	DEVEL. COST
3-inch	$850.36		$343.38		$488.33		$18.66
5-inch	296.83		123.41		155.05		18.37

Table XVI. Life cycle cost of the radar processor as a function of wafer size used in the fabrication of the memory chips. Costs are in millions of dollars.

SUBSTRATE	TOTAL LIFE CYCLE COST	=	LOGISTICS COST	ACQ. COST	DEVEL. COST
SOS	$654.41		$265.51	$370.34	$18.56
Bulk Silicon	296.83		123.41	155.05	18.37

Table XVII. Life cycle cost of the radar processor as a function of the substrate used in the fabrication of the integrated circuit chips. Costs are in millions of dollars.

USE OF CAD	DESIGN	TOTAL LIFE CYCLE COST	=	LOGISTIC COST	+	ACQ. COST	+	DEVEL. COST
None	Custom	$297.46		$123.41		$155.05		$19.00
Some	Custom	296.83		123.41		155.05		18.37
Much	Custom	296.20		123.41		155.05		17.73
None	Gate Array	296.84		123.42		155.06		18.37
Some	Gate Array	296.21		123.42		155.06		17.74
Much	Gate Array	295.89		123.42		155.06		17.41

Table XVIII. Life cycle cost of the radar processor as a function of the amount of computer-aided-design used in the design of the signal and control processor chips. Costs are in millions of dollars.

IMPACT OF ON-LINE TESTABILITY ON THE RADAR PROCESSOR COST

Of all the variables examined in this report, on-line testing and repair show the greatest impact on the life cycle of the radar processor. Table XIX shows the life cycle cost as a function of the degree to which fault detection, diagnosis, and repair can be accomplished on-board the aircraft. The data in this table assumes 95% of the failed boards repaired off-line are sent to the depot for repair. Table XX shows the life cycle costs for the same input as for Table XIX except that 5% of the failed boards removed for repair are sent to the depot. Fault coverage is defined to be the percent of total system failures which can be repaired on line.

The disposition of boards which are repaired off-line also impacts life cycle costs. Lower cost results when 95% of the boards that must be removed for repair are repaired at the base level rather than at the depot level.

Figure 4 graphically shows the cost data given in Tables XIX and XX. Note that on-line repair can affect life cycle costs by over a factor of 10. Also note that the level of depot repair affects the life cycle cost by less than 10%. In fact, Figure 5 shows the percent of life cycle cost difference between repairing at the depot 95% of the failures on boards that must be removed from the aircraft for repair, and repairing at the depot only 5% of the failures on boards. All other repairs made on boards removed from the aircraft are made at the base level.

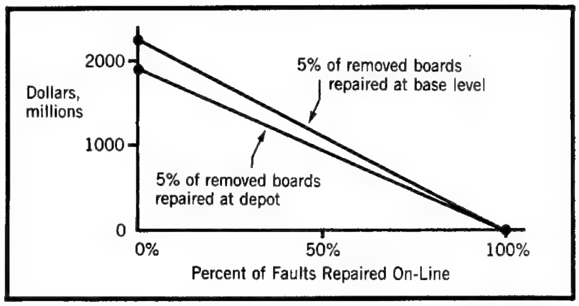

Figure 4. Life cycle cost of the radar processor as a function of the number of faults repaired on-board the aircraft.

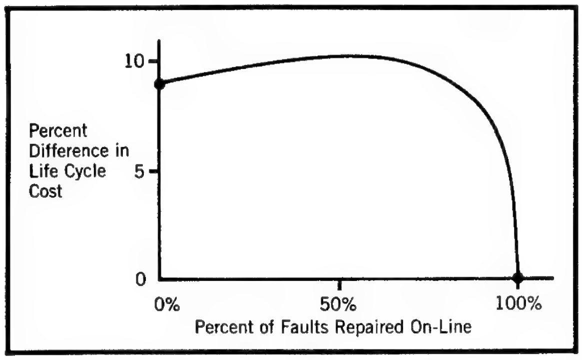

Figure 5. Difference in life cycle cost (percent) between sending 5% of removed failed boards and 95% of removed failed boards to the depot for repair.

SUMMARY

Of the factors examined in this article with respect to life cycle costs of a memory-intensive avionics system, the key problems appear to be the degree to which on-line testability and repair is implemented, the size of wafers used in the fabrication of the VHSIC chips in the system, the use of silicon-on-sapphire rather than bulk silicon

ON-LINE REPAIR	*TOTAL LIFE CYCLE COST*	=	*LOGISTICS COST*	+	*ACQ. COST*	+	*DEVEL. COST*
0%	$2120.88		$1947.46		$155.05		$18.37
25	1643.51		1470.09		155.05		18.37
50	1163.46		990.04		155.05		18.37
75	683.41		509.99		155.05		18.37
90	393.64		220.22		155.05		18.37
95	296.83		123.41		155.05		18.37
99	218.71		45.29		155.05		18.37

Table XIX. Life cycle costs of the radar processor as a function of on-line diagnosis and repair. 5% of the repairs made off-line are made at the base level. Costs are in millions of dollars.

ON-LINE REPAIR	*TOTAL LIFE CYCLE COST*	=	*LOGISTICS COST*	+	*ACQ. COST*	+	*DEVEL. COST*
0%	$1940.97		$1767.55		$155.05		$18.37
25	1506.73		1333.32		155.05		18.37
50	1071.83		898.41		155.05		18.37
75	637.60		464.18		155.05		18.37
90	375.98		202.57		155.05		18.37
95	287.66		114.24		155.05		18.37
99	217.01		43.59		155.05		18.37

Table XX. Life cycle costs of the radar processor as a function of on-line diagnosis and repair. 95% of the repairs made off-line are made at the base level. Costs are in millions of dollars.

continued on page 19

CAREER AND PERSONNEL INFORMATION

LOGISTICS OFFICER OPPORTUNITIES AND PROMOTIONS

During the past year, PALACE LOG career management officers enjoyed the privilege of being guests at a substantial number of CONUS bases, and a few overseas bases. From these visits, a number of concerns have been expressed by junior officers, some of which were simply misperceptions. The purpose of this article is to address two common concerns: promotion potential and career development opportunities for junior logisticians. Because these are the most important ingredients in career decision-making, all logisticians must know the facts and carry these facts to those who will decide on either holding to an Air Force career or making a return to the private sector.

Promotion Rates

The first and foremost concern is promotion rates. Each young (and not-so-young) junior officer lives in a microcosm. His or her beliefs reflect a narrow experience from one or perhaps two bases of assignment. Therefore, his or her beliefs about logistics officer promotions are keyed to those limited experiences. Most are surprised, usually astounded, at the facts. It is important to note that promotion data can be accurately analyzed even with a large number of variables. To simplify this, only one set of data is offered and explained and that is "primary zone first time eligible selection rates for officers performing duty in logistics career fields." Here are the facts. In the last five years, logistics officer select rates were: to major, 4,7% *below* the line officer rate (69.4% for loggies, 74.1% for line Air Force); to lieutenent colonel, 0.3% *above* the line officer rate (59.5% vs 59.6% respectively); and to colonel, 6% *above* the line officer rate (43.6% vs 37.6% respectively). These rates were computed by adding up all officers eligible for the first time from CY77 through CY81 promotion boards. If a comparison were made between logistics officers and other support career fields (rather than line officer), the results would be even more favorable. However, each of us competes with all the line officers in our year group, hence this is the most meaningful comparison. When given these facts, the skeptics may focus on three countering arguments.

The first argument is the "low" select rate for major. When the cumulative five year line officer select rate is 74%, a five percent variance is not terribly significant. Contrast this with the six percent variance for colonel promotions where the five year line officer select rate was 38%. The latter represents a greater significance than the "low" select rates to major. It is important to know and accept the fact that non-rated support officer promotions to major have historically been signficantly lower than rated promotions. This is *not* a rated vs non-rated issue. Because of the enormous investment in training, those officers selected for rated duty are subjected to a more careful screening. Hence, they tend to be more competitive at the first highly selective board—the majors' promotion board. The second argument is that rated officers performing duty in logistics career fields drive the selection rates up. It is true that rated supplement officers, as a group, enjoy greater promotion selection rates; most were selected for supplement duty based on demonstrated performance and potential, hence competitiveness. However, the rated supplement officers represent only five percent of the entire support and logistics officer force. A five percent population cannot significantly "affect" promotion rates. The third argument is ". . . my career field rate is lower than the overall logistics rate." There is NO counter argument here. Although there has been no effort to manage promotions by career field, the competitiveness of officers in some fields is evident by historical promotion trends. This may be due, in part, to the demographics of various year groups competing, and/or to the somewhat narrower and more specialized experience gained in a given career field. Further, it may be partially due to the relative visibility accorded some career fields in terms of OERs.

It would be incorrect to use historical promotion "trends" in predicting the future because promotions are not managed by career fields. The board process

selects officers who have demonstrated potential for increased responsibility, regardless of career field. Considerable importance is placed on the scope and depth of experience and how well officers performed in past duties and assignments. Half of this equation deals with experience opportunities, and this leads us to the second point in this article—perceptions of junior officers toward career development opportunities.

Career Development

Two axioms are commonly repeated about career development. They have the same "bottom line." Society, at large, accepts the premise that ". . . if you want a better job, you must demonstrate success in the one you already have." An Air Force version of this asserts:

> "The essence of career planning lies not so much in the selection of your next assignment as it does in the manner in which you are carrying out your present one. So far as you are concerned, the best career development job is the one you have right now."

Like the laws of science, these laws of career development are empirical. They warrant continuous repeating. However, some interesting facts provide insight for junior officers relative to the responsibilities facing them in the future. Fact one: lieutenant authorizations are only 13% of total authorizations, yet lieutenants represent 40% of all logistics officers. Fact two: captain manning is currently 59%; major manning is 86%; and lieutenant colonel manning is 80%. Fact three: captain manning will improve dramatically in the next two years as a result of promotions. However, field grade manning shortages will deepen. Hence, the critical need for experienced officers to fill highly responsible jobs exists now and for the foreseeable future. Where will this experience come from? We will have to build experience in our current and future junior officers. This means then that we must retain a very sizable portion of the current lieutenants and captains.

Many lieutenance are expressing concerns about upward mobility. Because of the sizable numbers in the CY77 through CY80 year groups, and the current experience shortages, many are already working in responsible captain positions. The most frequent concern is that they will repeat assignments at the same level; i.e. branch, squadron, etc. Reality says they are probably correct. Although some lieutenants (primarily prior service) have already moved to MAJCOM and intermediate command level staff jobs, the overwhelming majority will spend two to three assignments at lower levels. This is as it should be; to build "hands-on" experience at base level and to apply this experience in staff jobs. All logisticians should expect "return engagements" to field level assignments as they progress through their careers. This is essential in distributing experience where the requirements exist, and this keeps the officer in touch with the "real world." It follows then that career progression is not necessarily always upward mobility in terms of level of assignment. Instead, it is upward mobility in terms of level of responsibility. The junior officers must clearly understand this or their expectations will lead to disappointment.

From a PALACE LOG perspective, there will be no shortage of responsible jobs to accomodate the aspiring junior logisticians. Quite the contrary! By 1984, it will be common to see captains filling lieutenant colonel billets. A very few are already doing that. In the final analysis, those who perform their current duties enthusiastically and effectively (remember the earlier axioms?) are certain to move onward and upward to more responsible jobs. Those who spend all their time worrying about upward mobility are likely to worry less about their current jobs and end less mobile and on the short end of the stick.

In summary, the career development opportunities and promotion potential for logistics officers have never been better. The junior officers need to understand this, and the senior officers must both understand and encourage them. Collectively, we must bring this message to the lieutenants and junior captains who are, or soon will be, making career decisions.

Editor's Note: Variable promotion rates in the enlisted force will be discussed in our next issue.

Costs/Digital Processor continued from page 17

chip substrates, and the size of the memory chips. Some factors which seem to make negligible difference in the life cycle costs are design-related items such as the use of computer-aided-design in the chip design process, and the use of custom rather than gate array chip layouts. Furthermore, costs vary by only a small amount regardless of whether I^2L or bipolar technology is used to implement the signal and control processor chips in a highly memory-intensive system.

Although this study examines only a few of the many factors that impact life cycle costs of a representative VHSIC avionics system, it is obvious that many of the factors studied here can impact costs by anywhere from 2 to 10 times. The capability to test and repair by replacing VHSIC chips on-line in the aircraft is the largest contributor to lowering life cycle costs.

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A SYSTEMS VIEW OF MAINTENANCE PERFORMANCE

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As economic and political pressures generate complex levels of debate and concern about our expanding defense budget, military and government managers are being forced to examine alternatives for improving readiness and possibly reducing costs. Arguments at the center of the national debate on defense spending stem from the quality and quantity issues inherent in adding strength to our readiness posture. Disagreement develops when we try to derive a consensus around what is meant by "adequate posture," how much or how little that should cost, and what the relationships are between adequacy, effectiveness, and costs.

In response to these external forces, the Air Force must continue to examine its activities and seek ways to fulfill its mission and at the same time reduce, if possible, its spending. Since one third of the defense budget is spent on the delivery of logistics support, some attention has focused on this area.[1] Logistics support is costly, and for that cost it is imperative that the logistics system efficiently and effectively provides weapons systems that fulfill operational demands.

Without getting into a discussion over a broad definition of logistics, I think we can agree that the maintenance of the weapons systems as designed, procured, and supplied by the rest of the logistics system is, in and of itself, a critical function. It is not only a critical function, but when combined with rapidly rising manpower costs it is indeed an expensive one.[2] Owens et al. estimated that, in 1974, $1.5 billion was spent by the Air Force on avionics maintenance alone. Add the costs of organizational and field maintenance (no data available) to that figure, include the impact of inflation, and we can conservatively speculate that the annual cost of Air Force aircraft maintenance in recent years exceeded $5 billion. If we then bring into the equation the cost of missile maintenance and civil engineering maintenance, we are talking about costs far in excess of $5 billion; consequently, the potential for savings through improved maintenance is considerable.

The military has traditionally been labor intensive and has solved maintenance problems by adding manpower. When manpower was cheap that was a viable alternative, but given current manpower costs that alternative has lost its attractiveness. In addition, mistakes made elsewhere in the system eventually accrue in maintenance as it is the end of a sequential chain. Concomitantly, budget cuts, which result in manpower cuts, and other circumstances have eliminated the slack at the end of that sequential chain. Now when compounded mistakes are passed along the chain to maintenance, response capability is limited and the impact is more obvious and painful. Therefore, if one cannot add more people, the obvious alternative is to get more out of the people you have. Investigating what "getting more out of the people you have" means and how you might go about that is a project of current Air Force interest and is the focus of this paper.

This article investigates what the military and others have done to improve maintenance performance, considers those findings in a systems format, derives implicit assumptions, and then presents a model that displays a systems approach to individual maintenance performance. This model is at the descriptive stage and contains the basic factors necessary to study the problem of increasing maintenance performance while decreasing overall costs. I think this model is generally applicable to the management of maintenance in most complex organizations and I believe that the rationale behind the model is particularly appropriate. Before managers can successfully cope with complex systems, they must first come to grips with system processes and interactions between processes; this model provides one way of doing just that.

THE EVOLVING PROCESS

A review of the pertinent literature reveals that the Air Force has been investigating maintenance performance, in one guise or another and at various levels of support, since the early 1950s. Modrick compiled an annotated bibliography (two volumes) of a number of maintenance studies done between 1953 and 1958 that focused on task accomplishment as well as troubleshooting.[3] However, no summary recommendations were given in the material and the individual pieces are just that—pieces. This isolated, piecemeal studying of task performance typifies much of the research done in this area, and it is difficult to tell the efforts of the 1970s from those of the 1950s. The findings continue to cite the same problems of misuse of technical data and test equipment, poor troubleshooting or fault isolation techniques, and general maintenance ineptitude.

One line of research that has produced positive results is the ongoing research in the improvement of technical data. This work has focused first on task analysis and then on the development of detailed job guides to simplify task accomplishment. The work of Foley[4] and later Shriver and Foley[5] has focused on making the maintenance task easier to accomplish which can reduce costs in two ways—through reduced training and increased individual output. The work on detailed job aids seems well grounded; it can and has produced positive results, and it is one way of maintaining output, reducing costs, and dealing with the declining quality of the maintenance force. However, while this line of research is necessary, it is not, in and of itself, sufficient. It addresses only one part of a multi-part problem. As Foley[6] points out, by addressing only the technical data issue and ignoring the concomitant issues of selection, training, promotion, and complex technology, more problems are created than solved.

A third line of inquiry into maintenance peformance has been the use of systems theory or systems thinking to surround and grasp the complexities of the maintenance system. While some of systems genre' studies did not in fact adequately use systems thinking, three studies did. The first study utilizing systems thinking was by Hoisman and Daitch[7] who reviewed the literature relating personnel performance to systems effectiveness criteria. They reviewed over 400 reports and concluded that approximately 50 reports were usable for their purposes. Of those 50 reports the overwhelming majority were technical reports rather than articles from academic journals. The conclusion of their review was:

. . . as clearly borne out in the literature, there are few workable techniques for assessing personnel performance within the context of system effectiveness, and equally important, it has been only within the past few years that some of the critical factors comprising effectiveness have been identified. Put another way, unless one can identify the necessary and sufficient dimensions of system effectiveness, i.e., what constitutes system success, one cannot begin to relate personnel performance to system criteria. Until the two problems, assessing personnel peformance and identifying system requirements, are satisfactorily solved, useful and meaningful techniques of relating one to the other are obviously precluded.[8]

Unfortunately, Hoisman's and Daitch's conclusions are as apropos to the present as they were to the past.

The second study encountered that utilized systems thinking to examine maintenance was done by Drake et al.[9] They realized that the maintenance function is embedded in a larger, overall system and that inputs from that system could have significant influence on maintenance activities. They were aware of the organizational behavior literature that touches upon many of the organizational factors that were thought to impinge on individual behavior and utilized it to develop their perspective. They proceeded on the assumption that "a major reason for the previous lack of payoff in maintenance research and development is a relative neglect of important organizational factors."[10]

Drake et al. came to an interesting conclusion:

The results of our analysis indicate that the biggest payoff in improving military maintenance effectiveness and efficiency is not in introducing additional incentives but rather in reducing or eliminating the existing disincentives. Military mechanics like being mechanics and want to spend more time at it.[11]

Their conclusion indicates that the problem is not necessarily at the individual level of analysis but rather that part of the problem might be within the organization in which the individual is imbedded. The individual level of analysis is of course, necessary; but to embrace factors that meet the conditions of being *both necessary and sufficient,* one must also include the organizational levels of analysis and the interaction between them.

The third study found useful in developing the model used in this article is by Rice.[12] In the portion of his study discussing the weapons system acquisition process, Rice describes a scenario that relates directly to maintenance issues.

Present practices seem to reflect the convictions that:

1. Mission requirements can be firmly specified before development begins or technological capabilities are verified.
2. Important configuration decisions and technical specifications can be based reliably on design studies and analyses alone.
3. Subsequent development of the system will encounter no problems severe enough to upset cost and schedule projections. Unfortunately, there is little historical basis for such faith and considerable evidence that the policy it engenders is not very successful. In one set of 24 systems of the 1960s that embodied these assumptions, typical outcomes included cost growth (in constant dollars) averaging 40 to 80 percent, schedule slippages, and performance shortfalls.[13]

Rice further states that the same analysis for the 1970s' systems does not demonstrate significant improvement.

The above scenario has strong implications for the Air Force maintenance system because when a weapon system arrives on the flightline or at the silo the maintenance technician is going to have to make it function. If the acquisition process was in error concerning the above variables, why should it be assumed that the estimates of maintainability and reliability are any more accurate? One might seriously question whether the maintainability, including the human factors, ever received any indepth consideration. The aggregation across time of the above errors will accumulate in the technician's domain and will add substantially to maintenance costs. Rice comments further:

An almost inevitable consequence is a long (and costly) modification phase needed because there was insufficient opportunity to detect technical and operational defects, correct them, and incorporate changes before substantial numbers of production articles were delivered. During this phase, which may last for several years, system performance (including operational availability) typically falls well below the desired (or "required") levels. The result is not only that the forces must rely on systems that do not perform as expected (and, presumably, as necessary), but also that the DOD incurs high post-acquisition costs.[14]

Some of the high post-acquisition costs that Rice refers to are maintenance costs, presumably direct maintenance costs; however, along with direct maintenance costs go a number of indirect costs. What might be the impact of a long term weapons system modification on motivation, training, maintenance scheduling, operations, confidence in the maintenance system, parts availability, and a host of other variables? I think we can say, with some degree of confidence, that the impact on maintenance performance would be substantial and that the technician's "poor performance" (high cost) would be due to circumstances largely beyond his/her control. Rice's presentation again illustrates how false causal relationships can develop if you ignore the fact that maintenance performance is imbedded in a larger system.

This review is not a detailed coverage of all of the material examined; space does not permit that. It is a general brush across several literatures both within and without the defense community. As mentioned earlier, some of the previous research has been well done and it has been necessary. However, in and of itself, that research will provide only partial answers and may even produce dysfunctional results because it ignores critical interactions with other parts of the system in which the technician is imbedded.

DEVELOPING THE MODEL

The Air Force is generally viewed as a traditional hierarchy, and the research on the maintenance function has focused on the bottom of that hierarchy, but as viewed from the top. The Air Force hierarchy is representative of a tall organizational structure, having many vertical divisions, and, as such, probably has all the attendant characteristics.[15] Tall organizational structures are characterized as having one-way communication, narrow spans of control, many layers of supervision, and centralized authority. These characteristics contribute to the perception by those at the top of the organization as to what is going on at the bottom and vice versa. Those at the top assume that their world is representative of the bottom and draw conclusions accordingly. In reviewing the available literature, I have identified nine implicit assumptions that originate from this top/down perception. These nine implicit assumptions are:

1. The individual technician controls the majority of the variance in the maintenance situation.
2. The amount of variance in performance (output) is fixed.
3. A simple solution exists.
4. The "system" knows what it is doing.
5. Maintenance is a discrete, rather than a continuous, event.
6. Meanings are the same across levels of analysis.
7. All maintenance is aircraft oriented (in all of the documentation reviewed, neither missile maintenance nor civil engineering maintenance was mentioned).
8. The focus on discrete maintenance tasks is both necessary *and* sufficient to study performance.
9. The maintenance world is a simple world.

I believe that all nine of these implicit assumptions are *false* and that they stem from a biased view of maintenance. Also, since they are deducible from the research, they are inherent in the research; and if the research is based on false assumptions, there is then good reason to suspect the research. Therefore, since most of the research on Air Force maintenance peformance has been influenced by the biases of those viewing the system from the top, some new way of viewing old problems should be generated.

In grappling with the idea of viewing old problems in new ways, the question arises as to how we can improve individual performance. One answer is that for research purposes we could seek to optimize individual output. If we think of Air Force maintenance as a system comprised of some number of subsystems and if we invert that system and display the subsystems as supporting the individual, we begin to think about the inputs necessary to optimize individual output (see Figure 1). By dividing the Air Force system into six subsystems—management, supply, training, personnel, maintenance, and acquisition—pertinent to maintenance and displaying them as system inputs to an individual whose output is maintenance performance, we have a way to systematically investigate maintenance performance. It also becomes obvious that the subsystems are *not* independent but are interdependent, as shown in Figure 2. The exact extent of the interdependence is a research question, perhaps the

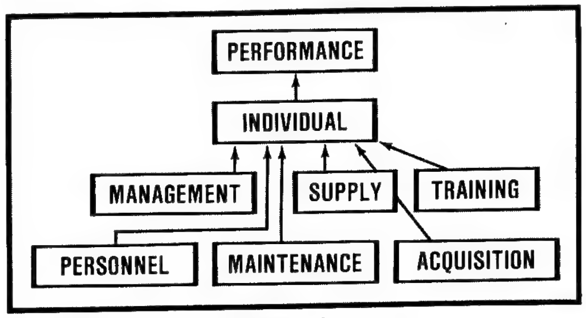

Figure 1

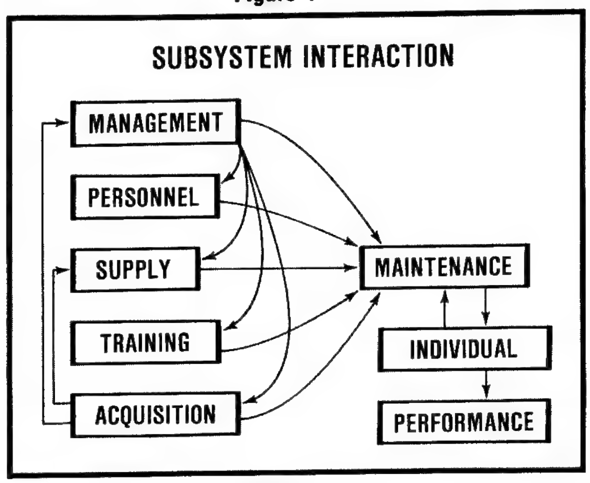

Figure 2

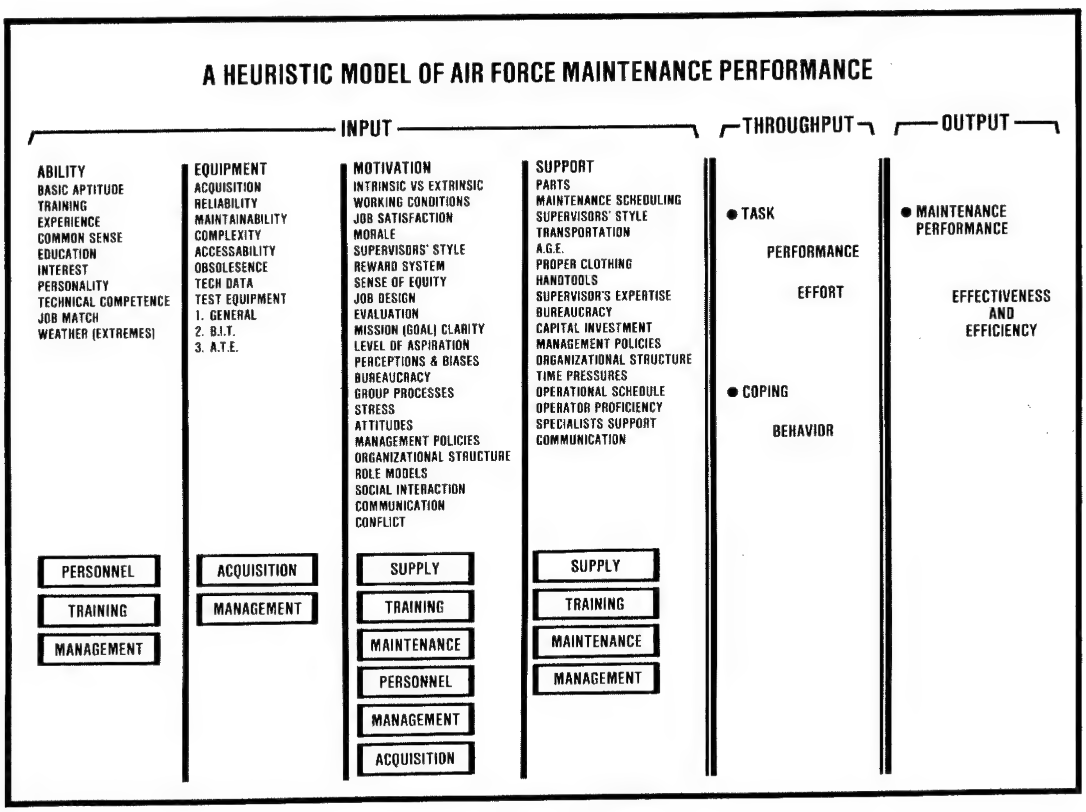

Figure 3

central research question, and it has not been investigated or acknowledged until now.

This model, then, focuses on the individual technician as a system having inputs, throughputs, and outputs. We can now follow the model development through each of these stages. The complete model can be seen in Figure 3, but remember that the model is still in the descriptive phase and as yet no effort has been initiated to quantify variables or interactions.

The breakdown of the Air Force system into six subsystems and the inversion of the system so that those subsystems provide input to the individual is revealing, but not specifically. A more precise view of what the inputs are is needed. By asking what are all the things that a technician needs to get the job done, a categorization of the inputs made to the individual emerges. The input portion of the model contains four categories—ability, equipment, motivation, and support—within which many of the factors that bear on individual task peformance can be expressed. (This model is artificially constrained at the boundaries of the Air Force and primarily bounded by those areas pertinent to maintenance). At the same time, we can plug one or more of the six subsystems into each of the four categories and begin to display some of the interlocking interdependencies. Under each of the four input categories is a list of variables that are thought to be crucial to successful task performance (output). As can be seen by examining Figure 3, this list is far more inclusive than previous research has indicated. There has been research focused on technical data, on reward systems, and on training but not on most of the other variables indicated, and particularly not on the interactions between them. This list is not intended to be all inclusive, as what should or should not be included is a research question. What is important is that now there is a framework within which to conduct this research. The framework also makes apparent that research that ignores the interactance, both vertical and horizontal, while necessary, cannot be both necessary *and* sufficient.

Viewing the subsystems as inputs begins to make obvious the failure of the previously identified implicit assumptions. Of special interest here are those assumptions concerning the amount of variance the technician controls. If we set the subsystems up on a time line from time zero to time n and determine the things that may go wrong before the individual gets them, we can then argue that the technician controls a small amount of output variance and in turn that variance may differ over time (see Figure 4).

Examination of Figure 4 indicates that errors could aggregate over time and also between subsystems. The accumulated error impacts on the individual technician at a time when he or she can also contribute error. However, the important point is that mistakes made five of six years ago in the acquisition process, in the assigning or training process, or in management policies may all combine algebraically to dominate the variance that appears to exist at the technician level. The technician may be performing 100 percent but the resultant system performance may still be poor (read high cost). For example, the weapon system may be (and generally is) plagued by unanticipated maintainability and/or reliability problems that consume a disproportionate percentage of

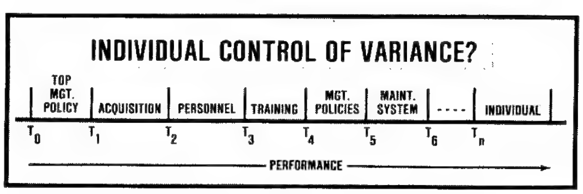

Figure 4

maintenance hours. The assigned technician is trained on C-5 equipment and now maintains an F-15 or some of its systems. The original spare parts buy was inadequate and there are few if any spare parts to repair the system. Top management decided to spend available resources to procure new end item weapon systems without the commensurate investment in O and M. Newly trained technicians are receiving reduced training that personnel in the field perceive as inadequate which in turn influences the tasks they are assigned which then interacts with motivation and commitment. Pressures from above to maximize flying hours induce local management to overschedule available manpower in turn leading to retention and morale problems which impact on maintenance performance. Personnel policies assign technicians to undesirable locations and to equipment with which they are not familiar or upon which they have not been trained. Furthermore, support at the local level—transportation, A.G.E., "expertise", parts, special tools and equipment, test equipment, scheduling—may be weak causing the technician to waste available maintenance hours waiting. At the individual level the technician may be performing to the best of his or her ability and the resultant performance may still be poor due to variables beyond the technician's control. Past research has implicitly assumed that the technician controlled all of the variance and that it was fixed. The assumed cause-effect relationships were much too simple.

Realizing that boundary drawing around and within models is somewhat arbitrary, we next proceed to the throughput stage of the model. Once the individual has the minimum inputs to the task, he or she then exerts effort to accomplish some specific task or relatively narrow series of tasks. The technician engages in a type of behavior that is more or less appropriate to successful accomplishment of the task at hand. How appropriate and successful that behavior is depends upon the technician, to some extent, and also upon the various inputs provided by the six subsystems. If the subsystems' inputs are inappropriate, so will be the technician's behavior. The technician may be poorly trained, lazy, or incompetent, but it is also possible that the weapons system has a faulty design, there are not enough spare parts available, or that the technician is being overtaxed due to poor scheduling. Explanations for poor performance (inappropriate behavior, high cost) have, in the past, focused only on the individual. This model makes it apparent that, to correctly analyze the inappropriate behavior, the individual *and* the system within which he or she is embedded must be examined.

The conclusion of the model is in the output stage, and here we come to grips with what we mean by performance. It is appropriate and necessary at this point to clarify the implicit assumption that meanings are always the same across levels of analysis (Number 6). When this research began, it was evident that one of the first issues that must be dealt with was the definition of performance. However, later it became apparent that the major issue was to be one of levels of analysis rather than definition because multiple definitions of performance exist which depend upon your position in the hierarchy. If you look at performance by level of analysis one can develop a series of definitions as follows:

1. *Individual.* Completed task or narrow series of tasks that leads to proper functioning of one system in one aircraft or missile.

2. *Shop.* Completion of a number of tasks by some number of individuals that leads to the proper functioning of a number of the same system (i.e., Doppler).

3. *Branch.* Completion of many tasks by many people that leads to the proper functioning of a grouping of related

systems (i.e., Comm-Nav, Fire Control).

4. *Squadron.* Completion of a large number of tasks that leads to the proper functioning of a large grouping of systems (i.e., AMS, FMS, OMS).

5. *Wing.* Completion of a large number of tasks that leads to the proper functioning of some number of an end item weapons system (i.e., F-16, Minuteman, B-52).

This line of reasoning can continue up the hierarchy and derive definitions for Division, Numbered Air Force, and Major Command. Instead of only a definitional issue, we have a definitional issue by level of analysis. The meaning of terms varies depending upon where you are in the hierarchy. A wing commander's definition is not the same as a flight line technician's. However, they are both "right," they exist simultaneously, and they have an impact on the system output—performance. If you are at the major command level using that level's definition of performance, it is no wonder that you would have difficulty improving performance at the technician's level; you are talking about different things. Performance can be measured, but it must always be stated at which level the measurement is being done.

Performance is the output of the system we have modeled, and it is at the individual level of analysis. Connell and Wollam[16] queried a range of managers at all levels of command as to their definitions of effectiveness. "All levels of command chose 'providing aircraft as required to meet mission requirements' as the most important measure of maintenance effectiveness out of the eight choices."[17] This commonly accepted definition of effectiveness will be used here as part of the performance measure, and performance (effectiveness) is stated as *providing an operational weapons system on demand.* Using definitions of performance by levels of anlaysis provides a way of measuring the output (performance) at several levels of analysis, including the individual level. After all, an F-15 ready for takeoff is really an aggregate of successful individual task accomplishments, and it is possible when necessary, to break that aggregate down into its component parts.

Performance here, however, has two dimensions—effectiveness and efficiency. What we have talked about so far is effectiveness or whether or not we have achieved our goal.[18] Efficiency is the ratio of inputs to outputs utilized to accomplish that goal. Not only is goal accomplishment considered (effectiveness), but the cost of the goal accomplishment (efficiency) is also important. For this model, then, performance is defined in terms of effectiveness (providing an operational weapons system on demand) and efficiency (providing an operational system on demand at the lowest cost concurrent with mission requirements).

The measure or measures of efficiency and effectiveness will eventually have to be addressed. The measures could be stated in dollars, manhours, mean time between failures, number of bodies assigned, some composite of these, or more than likely in a variety of terms depending on the purpose or level of analysis. Perhaps what to use for measures is another research question but one that is relatively straightforward compared to some of the other questions raised herein.

CONCLUSION

The military has traditionally emphasized effectiveness and ignored efficiency. Economic and political forces are now making it necessary to think more in terms of efficiency without degrading effectiveness. Like most well-run organizations, the Air Force wants to maintain or improve performance, but at the same time it seeks to lower the overall cost of doing business. The whole intent of this model, and subsequent research, is to maintain effectiveness while increasing efficiency.

If managers are to grasp the intricacies of complex systems, they must realize that viewing them and behaving as if the systems are simple ones are inadequate for the task; complex issues cannot be resolved using simplistic approaches. As Weick comments, 'If a simple process is applied to complicated data, then only a small portion of that data will be registered, attended to, and made unequivocal. Most of the input will remain untouched and will remain a puzzle to people concerning what is up and why they are unable to manage it."[19]

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Item of Interest

AFIT Publishes New Compendium

AFIT's School of Systems and Logistics through a special compendium committee under the direction of Col John A. McCann, USAF, ret. has produced a second edition of the *Compendium of Authenticated Logistics Terms and Definitions.*

Primarily of interest to AFIT students, this volume is a boon to all logistics researchers. Its 821 pages are filled with good data and useful information. The book itself is numbered AU-AFIT-LS-3-81 but it can be procured as ADA100091 from DTIC, Cameron Station, Virginia.

Calculation of Missile Availability Using Markov Chains

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ABSTRACT

Simulation techniques are being developed to assess and predict missile availability. They are very detailed, very accurate, and very expensive to exercise. Before an analyst forges ahead blindly into costly simulation, he should have a method to address missile availability theoretically. This proposed technique uses Markov chains to predict availability, n-step transitions, expected first passage times, and steady-state probabilities. An example is also included to illustrate the application of the technique.

Introduction

One of the primary concerns in the acquisition and deployment of new technology missiles (ALCM, GLCM, MX, etc.) is the prediction of availability. At present, several simulation models are being developed to perform such prediction; however, these models are, generally, very expensive to exercise. The following analysis is an inexpensive, theoretical alternative. Although this generic technique is not as dynamic as simulation, it is very flexible. I must acknowledge that, like the simulation models, this technique is based on predicted reliability parameters that are often inaccurate.

Methodology

Let $\{X_t\}$ be a set of random variables that represent the possible states or conditions that a missile can have. Then $\{X_t\}$ is a stochastic process. We can specify that the values that X_t can take on represent a possible state. To illustrate,

$$X_t = \begin{cases} 0, & \text{No failure; missile is operationally ready} \\ 1, & \text{Missile (minus engine) has a minor failure; degraded} \\ 2, & \text{Engine has a minor failure; degraded} \\ 3, & \text{Missile (plus engine) has a minor failure; degraded} \\ 4, & \text{System has a critical failure; can't operate} \end{cases}$$

This stochastic process, $\{X_t\}$, is a finite-state Markov chain since it has the following [1:352]:

(1) a finite number of states
(2) the Markov property,
(3) stationary transition probabilities,
(4) a set of initial probabilities, $P[X_0 = i]$ for all i.

The Markov property (2) is when $P(X_{t+1} = j \mid X_0 = k_0, X_1 = k_1, \ldots, X_{t-1} = k_{t-1}, X_t = i) = P(X_{t+1} = j \mid X_t = i)$, for $t = 0, 1, \ldots$ This means, simply, that it does not matter how the process arrived at the present state, but that transition to the next state depends *only* on being in the present state. The characteristic of stationary transition probabilities (3) is explained by $P(X_{t+1} = j \mid X_t = i) = P(X_1 = j \mid X_0 = i)$, for all $t = 0, 1, \ldots$, and for each i and j. This means that the transition probabilities do not change with time.

From this, we obtain a one-step transition matrix, P, which is (i + 1) by (j + 1), where i = j,

$$P = \begin{matrix} p_{01} & p_{02} & \cdots & p_{0j} \\ p_{11} & p_{12} & \cdots & p_{1j} \\ \vdots & & & \vdots \\ p_{i1} & p_{i2} & \cdots & p_{ij} \end{matrix}$$

where p_{ij} is the transition probability of going from state i to state j.

If we wish to find the probability of going from state i to state j in n transitions, this is [2:203]

$$p^{(n)}_{ij} = P[X_{k+n} = j \mid X_k = i],\ i, j = 0, 1, \ldots$$

for n = 1,2,3, ... We can easily calculate this from [1:354]

(1) $$p^n = p \cdot p \cdot p \cdots p = p^{n-1} \cdot P.$$

One of the most important things to know about this stochastic process, especially in predicting missile availability, is the expected first passage time from state i to state j; denoted μ_{ij}. This might be, for instance, the expected first passage time from an operationally ready missile (state 0) to a critically failed missile (state 4); μ_{04}. If all the states are recurrent and non-absorbing [1:358],

(2) $$\mu_{ij} = 1 + \sum_{k \neq j} p_{ik} \cdot \mu_{kj}$$

We also want to examine the long-run, steady-state probabilities. When all the states are ergodic (positive recurrent and aperiodic [1:360]),

$$\lim_{n \to \infty} p^{(n)}_{ij} = \pi_j$$

where $\pi_j > 0$,

(3) $$\pi_j = \sum_{1=0}^{M} \pi_i \cdot p_{ij},$$

(4) $$\sum_{j=0}^{M} \pi = 1.$$

These π's are the steady-state probabilities of the Markov chain. This is the probability of finding the process in a certain state, j, after a large number of transitions. Let's look at an example.

Missile Example

Let's assume that these missiles are stored and are inspected once a year. Let $\{X_t\}$ be the set of missile states at each inspection. During the inspection a missile is "activated" and runs for 3 hours on a test stand. It has constant failure rates that result in the following MTFB's (Mean Time Between Failure) and MTBCF's (Mean Time Between Critical Failure):

(1) MTBF (Missile-engine) = 54 hours
(2) MTBF (Engine) = 25 hours
(3) MTBCF (Missile-engine) = 185 hours
(4) MTBCF (Engine) = 40 hours

Assume that only failure free missiles (state 0) are considered available. We also assume that associated failures can occur during and after inspection.

We used these assumptions to calculate the one-step transition probabilities for the previously mentioned states. MTBF(1) corresponds to state 1, MTBF(2) to state 2, MTBF(1) and (2) to state 3, and MTBCF(3) and (4) to state 4. For this exercise we applied the widely used reliability expression,

$$R = e^{-\frac{t}{MTBF}}$$

to obtain estimates of p_{ij}. We did some subjective "factoring" to insure that the p_{ij}'s in each row totaled one (1). So we established $p_{ij} = 1-R$ for each associated MTBF. It is not this author's intent to detail all the methods of calculating the p_{ij}'s, nor is it to discuss their merits. Suffice it to say that we calculated the transition matrix, P,

	i \ j	0	1	2	3	4
	0	.608	.054	.113	.161	.064
	1	0	.632	.113	.161	.094
P =	2	0	0	.724	.177	.099
	3	0	0	0	.853	.147
	4	.911	.011	.034	.044	0

It is obvious that we have established a "policy" that a missile can't "get better" or "be fixed" unless it has a critical failure; i.e., $p_{10} = p_{20} = p_{21} = p_{30} = p_{31} = p_{32} = 0$. We have also specified that once it is "fixed", it can't have a critical failure before the next inspection; $p_{40} = 0$. These policies can easily be changed by establishing the associated transition probabilities.

First, consider what is the probability of going from state 0 to state 4 in 4 inspections. Using equation (1), $P = P \cdot P \cdot P \cdot P = P^2 \cdot P^2$, we get

	i \ j	0	1	2	3	4
	0	.283	.061	.185	.392	.095
	1	.173	.173	.173	.383	.099
P^4 =	2	.178	.013	.307	.399	.101
	3	.225	.018	.044	.600	.111
	4	.317	.064	.228	.353	.090

Hence, $p_{04}^{(4)} = .095$, or there is a 9.5% probability of a missile going from state 0 to state 4 in 4 inspections.

Next, consider the expected first passage time from state 0 to state 4; μ_{04}. From equation (2) we get

$$\mu_{04} = 1 + .161\mu_{34} + .113\mu_{24} + .054\mu_{14} + .608\mu_{04}$$

$$\mu_{14} = 1 + .161\mu_{34} + .113\mu_{24} + .632\mu_{14}$$

$$\mu_{24} = 1 + .177\mu_{34} + .724\mu_{24}$$

$$\mu_{34} = 1 + .853\mu_{34}$$

Solving these simultaneous equations, we get

$$\mu_{04} = 8.77$$

$$\mu_{14} = 8.14$$

$$\mu_{24} = 7.98$$

$$\mu_{34} = 6.80,$$

which means that we would expect 8.77 inspection periods for a missile to pass from state 0 to state 4 for the first time.

Finally, what are the steady-state probabilities, π_j? From equations (3) and (4) we get

$$\begin{aligned}
\pi_0 &= .608\pi_0 &&&& +.911\pi_4 \\
\pi_1 &= .054\pi_0 & +.632\pi_1 &&& +.011\pi_4 \\
\pi_2 &= .113\pi_0 & +.113\pi_1 & +.732\pi_2 && +.034\pi_4 \\
\pi_3 &= .161\pi_0 & +.161\pi_1 & +.177\pi_2 & +.853\pi_3 & +.044\pi_4 \\
\pi_4 &= .064\pi_0 & +.094\pi_1 & +.099\pi_2 & +.147\pi_3 & \\
1 &= \pi_0 + & \pi_1 + & \pi_2 + & \pi_3 + & \pi_4
\end{aligned}$$

This yields

$$\pi_0 = .241$$

$$\pi_1 = .038$$

$$\pi_2 = .127$$

$$\pi_3 = .490$$

$$\pi_4 = .104.$$

This means that after many inspections, we would have a 24.1% probability of finding an operationally ready missile. By our definitions and assumptions, the missile availability is .241. By establishing different criteria, and saying that maintenance on missiles in states 1 and 2 will put the missile in an operationally ready status, the availability, under this definition, is $\pi_0 + \pi_1 + \pi_2 = .406$.

Applications

Again, the intent here was not to discuss the calculation of the transition probabilities but to show that Markov chains can be used to predict missile availability. This can be applied to any system provided that the user can establish the possible states of concern. They will differ from system to system.

The transition probabilities can readily be changed to examine sensitivities. The user can also incorporate the concept of fault detection and fix. For example, instead of $p_{10} = p_{20} = p_{30} = 0$, one can specify a probability that a fault is detected and fixed. So now we could have a missile being returned from a degraded mode to operationally ready.

It is also very simple to compare inspection policies. If the times between inspections were to be altered, the p_{ij}'s would change. Then the analyst could calculate the μ_{ij}'s and π_{ij}'s to compare the various inspection policies.

Conclusions

This technique is simple to understand, use, and program on a computer. It is flexible. It is an inexpensive alternative to simulation. It can be exercised early in a system's life to highlight potential problems. It gives the analyst the means to compare various assumptions, criteria, and policies. It should be used as a means of examining several areas before blasting off into costy simulation.

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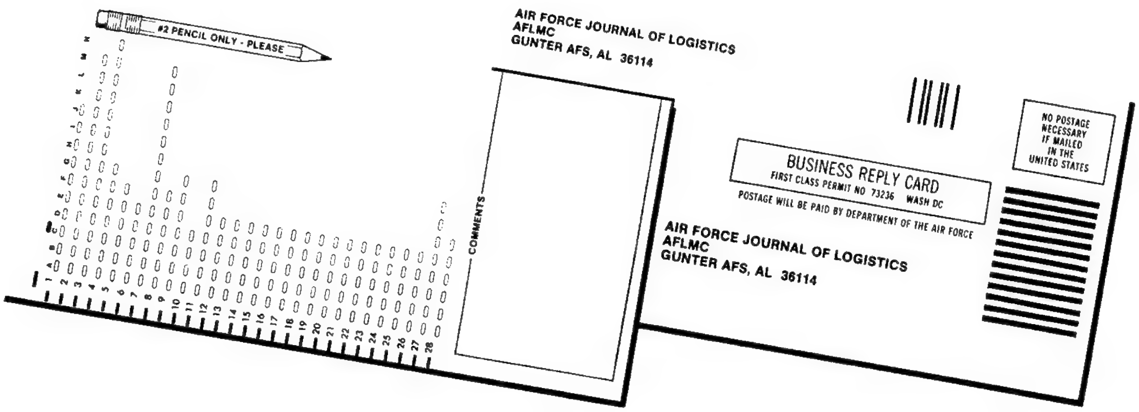

The 1981 AFJL Reader Survey

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Reader Survey Results

The Spring 1981 issue of the *Air Force Journal of Logistics* included a reader survey. In addition to satisfying AFR 5-1 requirements, the survey had several specific purposes: to determine if the *AFJL* was reaching its primary target readership (the professional core of officers, civilians and NCOs in the logistics community) and other interested Air Force, military and civilian readers concerned with Air Force logistics issues; to enable that readership to evaluate, in depth, the effectiveness of the *AFJL;* and to identify areas where the *AFJL* could improve or place more emphasis to better serve the Air Force logistics community.

Specific areas addressed in the survey included identification of readership by status, grade and fields of work; distribution, depth of readership; content and production quality; overall assessment, utility and value. In addition, opportunity was provided, through specific questions and solicitation of comments, for respondents to suggest future coverage.

Objectives as ambitious as these must be pursued with a fairly lengthy and thorough set of questions. Such factors tend to hold down the response rate to purely voluntary surveys. A machine-readable, mailback survey card was used both to overcome that tendency by making it as easy as possible for those readers who were interested in responding to do so and to facilitate the analysis and detailed breakout of the responses that were made. While the total number of cards returned (247 as of 28 Aug) was not as many as hoped for, the decision to opt for thoroughness and quality in the survey, rather than shooting for a large number of responses to a superficial exercise, was rewarded by some extremely interesting and useful results which will be shared with *AFJL* readers in the next few pages.

In fact, the survey was conducted and its results are being reported using the basic editorial policies that have guided the *AFJL* from its inception: a critical and sound assessment was encouraged; allowance was made for consideration of hard facts and well-reasoned personal perspectives and insight; and good, bad or indifferent, the results are provided in enough detail to enable readers to understand the rationale for the conclusions reached and to develop other interpretations as they see fit.

In short, the survey was invitation to give the *AFJL* the same thorough, constructively critical examination that the *AFJL,* as a professional journal, provides for broader Air Force logistics issues. Prior knowledge of a few areas (target readership, contents, known distribution, etc.) permitted hypothesizing about the expected results to some survey questions. These "educated guesses" are also included below. Finally, this discussion has been written to provide readers with not only the results, but with additional insight to the editorial policies and production details of the *AFJL*.

(The total responses to each question vary as a result of a few respondees skipping some questions and providing multiple responses to others.)

1. Based on the existing population composition of the known *AFJL* distribution, it was hypothesized (correctly) that the most responses would be from the Active USAF, USAF Civil Service, Air National Guard and USAF Reserve, and Business/Industry in that order.

1.

Status	
Active USAF	116
ANG or USAFR	32
Other U.S. Military	1
Other Nation Military	--
USAF Civil Service	58
Other DOD Civil Service	5
Non-DOD USG Emp.	1
Education	1
Business/Industry	28
Other	1
TOTAL	243

2. In terms of rank/grade, the most numerous responses expected were from the company grade military, GS 9-12 civilian, GS 13-15 civilian and field grade military. In fact, the survey revealed a high response/readership among the relatively smaller populated senior military and civilian grades. This can be interpreted in several ways. It could indicate an expected strong sense of professional responsibility to logistics and interest in broad issues among those in middle and upper leadership positions in logistics. There is also the possibility that these response rates reflect the way the latest copy of most publications is often processed through an organization: to the senior personnel first. This latter is supported by the fact that *all* survey responses received by the *AFJL* to date were made using the mailback card, despite the encouragement to reply to the survey even if the card was missing.

2.

Rank/Grade	
General Officer	2
0-4 through 0-6	83
0-1 through 0-3	34
Warrant Officer	--
E-7 through E-9	16
E-1 through E-6	8
Gov't civilian appointee	7
GS-16 through GS-18	1
GS-13 through GS-15	30
GS-9 through GS-12	28
GS-1 through GS-8	2
Wage Grade	--
Non-government Employee	29
TOTAL	240

3. The responses to this question indicated an *AFJL* readership well distributed among the major diverse areas of logistics. This distribution, plus the relatively high response from logisticians working in logistics plans/programs and two or more functional areas is perhaps reflective of the multiple field, total logistics system scope of the *AFJL*.

3.

Field	
Supply	29
Maintenance	30
Contracting	12
Transportation	17
Distribution	2
Logistics Plans/Programs	46
Systems Acquisition	11
Engineering and Services	7
Resources Management	14
Operations	1
Education/Training	14
Research/Studies/Analysis	8
Two or more of the above	44
Other	13
TOTAL	249

4. The approximate known distribution of the Spring issue containing the survey was, in order of size, as follows: the Air Force PDO system distributed the most copies - 2540, followed by the Superintendent of Documents to Federal Depository Libraries - 1448, the OCPO to logistics executive cadre members - 820, the AFLMC/*AFJL* - 400, and the Government Printing Office to subscribers - 108. It was hypothesized that the responses identifying the distribution method would be in the same quantitative order with the exception of the Federal Depository Library issues. For the library issues, unlike the other groups, there is no guarantee of a specific logistics readership; and because most of the library copies were in periodical rooms of Federal depositories, a reluctance to deface permanent library reference material by tearing out the card could, and apparently did, operate to restrict the responses returned from that area.

The response results were as hypothesized with the exception of the reversal of the order of the OCPO and AFLMC distribution responses. At least two factors may have contributed to this result. The Education With Industry portion of the AFLMC distribution was provided an additional response card to give both the industry and Air Force personnel associated with the program an opportunity to respond. Second, some personnel receiving the OCPO distribution copies may have responded to a PDO distributed copy received earlier in their organization.

In any event, the responses to this question also permitted determination of specific response rates that were much more meaningful than the overall

4.

Distribution Method	
Official USAF distribution (PDO)	136
GPO subscription	17
OCPO distribution	30
AFLMC distribution	37
Library	3
Friend	5
Unknown	15
TOTAL	243

response rate (excluding Depository Library copies) of 6.4% to the survey. Those specific rates were as follows: USAF(PDO) - 5.3%; GPO subscribers - 15.7%; OCPO Logistics Executive Cadre - 3.7%; and AFLMC/*AFJL* distribution - 9.3%.

5. The current approved PDO reader to copy distribution ratio for the *AFJL* is fifteen to one. With an estimated 35-40,000 in the primary target reading audience of the *AFJL* and the AF PDO requirements established at 2540 for the Spring issue, this *appears* to be an accurate ratio. Based on this alone, the most responses to the reader to copy adequacy question should have occurred in the 11-15 range. However, because of several other known factors, it was hypothesized that the most responses would occur in the choices below this range.

First, the 15:1 ratio is considerably higher than most other government journals (usually printed at 5 or 7 copies per reader) and has resulted in many organizations receiving too few copies to serve a large number of interested readers. Direct feedback during the past year has indicated that some were not reached at all. In some cases, the organization had not established their requirements for the *AFJL* with their local PDO; this, of course, is easily corrected. In other cases, the requirements established were inadequate if based, in fact, on the 15:1 ratio.

The other factor influencing the hypothesis in this area was the known distribution of the survey issue to a large number of individual logisticians (through OCPO and GPO) rather than to logistics organizations. While it was possible and, as the survey results revealed, true that these copies were passed on to other readers, it was not likely that any one would reach 15 others.

The total estimated readership of the *AFJL,* based on the responses to this question, is in the 30-50,000 range.

5. *Reader/Copy*

Only myself	19
One to five others	104
Six to ten others	72
Eleven to fifteen others	20
Sixteen or more	19
Do not know	8
TOTAL	242

6. More responses were expected for the "Enough" selection to this question simply on the basis that more responses would come from readers in organizations receiving an adequate number of copies than from those receiving too few or no copies. Based on the factors considered in question five, the next most numerous responses were expected to indicate "Not enough" and "None."

That almost one-fourth of the respondees indicated that not enough or no copies were reaching their duty section through the PDO system partially confirms the inadequacy of the current authorized reader to copy distribution ratio established in the PDO system. A request has been made to change that basis of distribution ratio to 7:1 for the *AFJL*.

6. *Distribution Adequacy*

Enough	156
Not enough	30
Too many	5
None	29
Not eligible	16
TOTAL	236

7. This question was included in the survey to gauge the distribution time between printing of an issue and receipt by readers dependent on various distribution means. Past experience and selective monitoring of the distribution channels had revealed a lag of from four days to six weeks.

Because of delays due to the unusual nature of and stringent printing specifications and requirements associated with production of the response cards, the issue was not delivered out by the printer until mid-May. At that point, the question became invalid.

This did not prevent 30, or roughly 12%, of the responses from indicating that the issue was seen prior to 11 May, an impossibility. Any attempt to explain why this occurred or what it means would be pure speculation.

7. *Distribution Speed*

Before 5 April	9
6-10 April	1
11-15 April	2
16-20 April	2
21-25 April	1
26-30 April	1
1-5 May	8
6-10 May	6
11-15 May	1
16-20 May	6
21-25 May	10
26-31 May	32
After 1 June	162
TOTAL	241

8. The purpose of this question and the following one was to gauge the depth of readership and extent of familiarity with the *AFJL*. It was hypothesized that more respondees would have read from four to six issues than from one to three on the basis that early and continued familiarity with

the *AFJL* would have been one influence on completing the survey. In fact, the responses were almost evenly divided. Some of the distribution inadequacies discussed above may have contributed to this, reducing the likelihood that every reader who saw the first issue received each issue subsequently published.

The response to this question and the next one were highly valuable in analyzing the judgment of effectiveness and usefulness questions in the last part of the survey.

8. *Issues Seen*

This is the first	27
Two	47
Three	52
Four	44
Five	24
Six	45
TOTAL	239

9. If any periodical, but especially a professional journal, is to be effective and worth the effort of publication, it must be read. A journal like the *AFJL,* that attempts to encompass as many diverse professional interests as exist within the Air Force logistics community, could conceivably be haphazardly read by readers zeroing in on the one or two items in each issue pertaining to their own personal interests or narrow area of specialization, completely disregarding the rest of the issue. If the *AFJL* is to help create an awareness and increase the understanding of the total logistics system, readers, for whatever reasons, must read at least half of every issue, regardless of their immediate functional interests. Thus it was hoped, as much as hypothesized, that more responses would indicate that half or more of every issue was being read by most readers. This is the case.

9. *Amount Read*

All	41
Most	89
About half	49
One or two articles or departments	37
Very little	10
Look at but seldom read	8
Sometimes little; sometimes most	4
TOTAL	238

10. This question was included to determine if any long-term value of *AFJL* contents was being recognized. There is no requirement to retain any recurring publications, and many are, in fact, thrown away. However, about three-fourths of the *AFJL* issues printed are being saved for future reference and use.

It will probably be worthwhile to include in the fifth or tenth year anniversary issue of the *AFJL* an index of the previously published issues. In the meantime, the contents of each issue are being indexed in the *Air University Library Index to Military Periodicals,* the *Index to U.S. Government Periodicals* and the Defense Logistics Studies Information Exchange. Back copies of the *AFJL* are now available on microfiche through the publishers of the *Index to U.S. Government Periodicals.*

10. *Issue Retention*

Yes	137
No	54
We are going to	25
Do not know	25
TOTAL	241

11. This question was included to determine if the *AFJL* was of professional value and use, and if so, how. Multiple responses were allowed in recognition that different contents could be useful in different ways to the same reader. The overwhelmingly positive responses to this question from most readers balances the few specific "no value" comments received, some which were published in the Summer issue. These results also help explain the high retention of back issues indicated by the responses to the previous question.

11. *Value*

Have used some contents in my work/professional life	73
Some ideas/information may be useful in the future	76
Educational-increased my understanding of AF logistics	106
Informative-usually learn something new from each issue	108
Interesting	60
Uninteresting	6
No value	9
TOTAL	438

12-27. Most of the remaining questions were included to enable readers to make a complete subjective evaluation of every aspect of the *AFJL.* With few exceptions, there was little basis other than the fundamental goal of doing as well as possible in each aspect in each issue, upon which to hypothesize how those aspects would be rated. Thus no results hypotheses were developed.

Both the contents and appearance of the *AFJL* have been heavily influenced by the basic editorial policy of taking a professionally serious and thorough approach to Air Force logistics. The *AFJL* has been designed to distinguish it from other publications in a way that permits the maximum amount of substantive content in each issue (as opposed to unit and individual puffery, nice to look at pictures and art work, and "soft" information such as organization schematics, current manning charts and lists, endless lists, of promotions, retirements, graduations, awards and decorations, transfers, *et cetera, ad infinitum,* that are available elsewhere and contribute little to the advance of professional thinking in any field).

The simple objective of questions 12-27 was to determine the overall reception and collective assessment of one professional journal, the *AFJL*, published under such a policy. The results are, for the most part, self-explanatory.

12-13. The bulk of each issue is printed in 9 and 10 point type. Given the choice (necessitated by space constraints) of printing an accepted article, item of interest or department in smaller size type (6, 7 or 8 point) or not printing it at all, the decision has consistently been made in favor of the former. The skew of responses toward lower ratings in question 13 reveals this as an irritant to *AFJL* readers. Use of reduced type size will be minimized and eliminated where possible.

14. The proofreading assessment was included in this series of questions as a result of severe criticism of this area in previous issues of the *AFJL*. The ideal of every publication, of course, is for no typographical errors to survive final proofing. Some often do, however, to the detraction of the publication's overall effectiveness if too extensive. Interestingly enough, this aspect received an extremely high overall rating. Apparently, the focus of most readers' attention has been where it should be - on content.

15. New graphics in each issue is limited to that necessary to provide information integral to the major articles or portray complex ideas and relations discussed in those articles. Thus, here as elsewhere, for both economic and editorial reasons, the *AFJL* has opted for excellence and essentiality rather than large amounts of unessential, possibly mediocre filler.

16-18. The *AFJL* has continually sought to publish a variety of high quality, in-depth articles on Air Force logistics topics in each issue. It was hoped that the inclusion of the content "qualities" among the factors to be rated would help prompt specific comments in this area. They did. While the overall ratings in each of these areas was relatively high, some comments were written to the effect that the level of contents of the *AFJL* was beyond the capabilities of the average logistician. If this is so, then this is one area where the change must come outside the pages of the journal. To pretend that the logistics problems and issues facing the American military are any less complex and can be understood and solved with any less rigorous analysis than is portrayed in *AFJL* articles is to invite future military disaster. The "average" logistician during the next few years had better combine extensive practical experience with a full range of analytical and quantitative ability if the best logistics and military decisions are to be made.

19-24. Of all the other easily identifiable components of the *AFJL* contents, the "USAF Logistics Policy Insight Department" received the largest number and proportion of high (good and excellent) ratings. An interesting exception occurred among company grade officer readers who gave ratings to the "Current Research Department" higher than those they gave to the "Policy Department."

12. *Layout*

Poor	2
Unsatisfactory	4
Satisfactory	68
Good	99
Excellent	67
TOTAL	240

13. *Type*

Poor	7
Unsatisfactory	19
Satisfactory	84
Good	79
Excellent	54
TOTAL	243

14. *Proofreading*

Poor	1
Unsatisfactory	4
Satisfactory	41
Good	102
Excellent	90
TOTAL	238

15. *Graphics*

Poor	2
Unsatisfactory	9
Satisfactory	70
Good	107
Excellent	48
TOTAL	236

16. *Article Quality*

Poor	1
Unsatisfactory	6
Satisfactory	75
Good	100
Excellent	53
TOTAL	235

17. *Article Thoroughness*

Poor	--
Unsatisfactory	5
Satisfactory	80
Good	108
Excellent	42
TOTAL	235

18. *Article Variety*

Poor	4
Unsatisfactory	13
Satisfactory	100
Good	85
Excellent	31
TOTAL	233

19. *Current Research Dept.*

Poor	4
Unsatisfactory	4
Satisfactory	90
Good	88
Excellent	47
TOTAL	233

20. *Career and Per. Dept.*

Poor	5
Unsatisfactory	14
Satisfactory	97
Good	81
Excellent	36
TOTAL	233

21. *USAF Log Policy Dept.*

Poor	2
Unsatisfactory	13
Satisfactory	68
Good	96
Excellent	58
TOTAL	237

22. *Specials*

Poor	1
Unsatisfactory	5
Satisfactory	109
Good	89
Excellent	28
TOTAL	232

23. *Items of Interest*

Poor	5
Unsatisfactory	10
Satisfactory	97
Good	86
Excellent	32
TOTAL	230

24. *Back Cover Quotes*

Poor	6
Unsatisfactory	6
Satisfactory	98
Good	84
Excellent	42
TOTAL	236

25-26. One of the more pleasant, and unexpected, revelations of the survey was the apparent synergistic effect of the individual elements of the *AFJL* when they operate together as a professional journal. The three questions (12., 25. and 26.) that required an evaluation of the overall effectiveness of the *AFJL* (in terms of general appearance, relevance and purpose achieved) received ratings higher than eleven of the twelve components evaluated separately (the exception being the proofreading anomaly).

25. *Overall Relevance*

Poor	6
Unsatisfactory	12
Satisfactory	65
Good	115
Excellent	41
TOTAL	239

26. *Overall Purpose Met*

Strongly Disagree	4
Disagree	13
Undecided	28
Agree	162
Strongly Agree	25
TOTAL	232

27. Because the comparison called for in this question was non-specific (*AFJL* to "other logistics publications"), the results simply indicate in one more way the general reception of a professional journal published with the level of approach and editorial policies that shape the *AFJL*. Perhaps the most interesting finding of this question was the discovery that for at least one out of eight readers the *AFJL* is the only logistics publication read. Further examination of the results revealed that nearly half of those selecting the "not familiar with any other logistics publication" response came from two groups - business/industry and company grade officers. In fact, these two groups made this indication at a rate two and a half times greater than the rest of the survey respondents.

27. *Rating Comparison*

The best	5
Among the top few	53
Better than most	98
Average	39
Worse than most	4
Among the worst	2
The worst	1
I am not familiar with any other logistics publications	32
TOTAL	234

28. The possible additional features identified in this question were either part of the initial concept of the *AFJL* or were suggested during its first year of publication. The limited number of pages authorized for each issue of the *AFJL* has been a primary factor precluding expanded *AFJL* coverage in these areas. As initiated in the previous issue, however, substantive letters to the editor will be published when received. Addition of other new departments, despite the interest indicated by the responses to this question, will be affected by the outcome of the current review (and directed reduction of costs) of the total DOD recurring publication effort.

28. *Future Coverage*

Analytical Tips	72
Book Reviews	68
Calendar of Events	91
Letters to the Editor	96
Other	27
None-leave it as is	28
TOTAL	382

Some of the most positive and negative comments received were published in the Summer 1981 issue. There were others of both kinds. Many of the suggestions for future coverage were from readers requesting more articles on topics in, naturally, their functional areas. The single most common suggestion was for greater *AFJL* coverage of direct interest and application to base-level, first-line logisticians.

All of the survey suggestions will be well-heeded, and other possible changes considered, as the *AFJL* proceeds under new editorial guidance during the coming years.

READER EXCHANGE

Transition

With this issue the *AFJL* enters a new era as Lt Col Pember W. Rocap leaves the editor's chair to prepare for a security assistance assignment to Rome, Italy. He leaves after five years of building and expanding the *Journal* to serve the professional Air Force logistician and striving to provide an unbiased and open forum for the presentation of research, ideas, issues and information of concern to the Air Force logistics community.

Your new editor, Major "Ted" Kluz, comes fresh from a two-year stint as associate editor of the *AU Review*. He has prior experience in security assistance/Saudi Arabia and on the faculties of ACSC, AFIT and RAF College Cranwell. His goal at the *Journal* is to continue to search out the most compelling and valuable information for the professional logistician. We will also continue our efforts to expand the content of the *AFJL* to provide the broadest possible coverage of topical logistics information. However, as with any professional military journal, you the readers, are the authors of the *Journal*. The future content of the *AFJL* therefore depends on your willingness to have your work and ideas examined and judged by other members of our profession.

From the Editor

To accommodate the reader's survey in this issue, the *Current Research Department* has been moved ahead to our Winter issue. Included in that department are the AFIT School of Systems and Logistics theses and the Air Force Human Resources Laboratory projects. We apologize for the inconvenience.

CEMS REVISITED

1. First, let me applaud Capt Somers for his descriptive article on "CEMS." Basically, he has got the gist of the topic and has done an excellent job of getting across his knowledge. Unfortunately, I believe, some elements have been overplayed and some woefully underplayed.

2. CEMS was an outgrowth of the absolute necessity to track the life limited components in the F100 engine. In November of 1974, when the Eagle Jet arrived at Luke Air Force Base, there was a need to track the modules and module components but no computer program existed to colocate, compile and/or store the voluminous data. Indeed, TAC and the enlisted men and women of the 58th Tactical Training Wing at Luke tried to keep manual records. You can imagine the volume of data to be recorded and updated daily—all done manually. Then Capt Bob Carnes, Headquarters TAC, LGMM, extended the TAC MILAP Program to include F100 engine record keeping. This system evolved out of necessity and was later improved and built upon. Today, it is CEMS.

3. In 1978-79, the Air Force Inspection and Safety Center conducted a Functional Management Review (FMR). The FMR's objectives were multiple, one of which was to validate the need for CEMS. The FMR clearly pointed out the need and made several recommendations that, if adopted, would improve the system. It is evident that those recommendations were not original and all parties involved with the system coalesced and promulgated those improvements.

4. Dr. Ben Williams, then AFLC/LOP, was the CEMS guru. He spent several years working toward total adoption of CEMS. He worked the Data Automation Requests (DARs), defended budget requests, etc., to ensure CEMS reaching the point it is today. CEMS is approaching Phase IV, the diagnostic element. This element, it is widely agreed, will be the toughest nut to crack.

5. On Condition Maintenance (OCM) is a tough-to-define acronym. To some maintenance folks it means one thing, while to an engineer something entirely different. Almost everyone agrees elements of OCM, like SOAP, are true participants and players. Yet, we still have finite life limits in our hardware which dictate specific intervals of inspection and/or removal. No airborne turbo machinery now built can last forever "on the wing" of an aircraft. All agree, though, we need a methodology, technique or system to tell us the relative health of our engines. Within the engine community there has been an on-again off-again attempt to develop a diagnostic system to do this job. Today, in ASD/YZL, we are working on Turbine Engine Monitoring System (TEMS)—trying to lay down a general requirement and specification. Hopefully, it will be fully integrated with Phase IV of CEMS.

WILLIAM C. MORRISON, Lt Col, USAF
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** AUTOVON 785-2492 will get you Col. Morrison's office for further discussion of CEMS, TEMS, and parts tracking.*

POE HIT THE MARK

I have just finished reading General Bryce Poe II's article in the Summer 1981 *Air Force Journal of Logistics* and could not allow the opportunity to comment on it pass. Not only is General Poe a great American and partriot, but a gifted thinker with a keen insight to the problems we face in the future. As a logistics inspector of the Air Force Safety and Inspection Center, it is very clear how the problems we face with experience contrast with the article on "Chinese Logistics Doctrine - A Reflection of National Imperatives." One can only hope that experience at dying is not a prerequisite for winning a war.

I would like to cast my vote for the article on General Poe's comments as the most significant article in the Summer 1981 issue of the *Air Force Journal of Logistics*.

NEWELL C. McMANUS, JR., Major, USAF
HQ AF Maintenance Inspector

** Please see the award announcement in this issue.*

"Alexander better understood the capabilities and limitations of his logistic system than perhaps any other commander, before or since. . . . Their achievement (Alexander and his staff) becomes more impressive when one remembers the barren terrain through which the army often marched, the limitations of overland transport, and the low level of agricultural production . . . ."

Donald W. Engels. *Alexander the Great and the Logistics of the Macedonian Army.*

Air Force Journal of Logistics
Air Force Logistics Management Center
Gunter AFS, Alabama 36114